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Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers, 2nd edition

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ABSTRACT

Forests across the United States are expected to undergo numerous changes in response to the changing climate. This second edition of the *Forest Adaptation Resources* provides a collection of resources designed to help forest managers incorporate climate change considerations into management and devise adaptation tactics. It was developed as part of the Climate Change Response Framework and reflects the expertise, creativity, and feedback of dozens of direct contributors and hundreds of users of the first edition over the last several years. Six interrelated chapters include: (1) a description of the overarching Climate Change Response Framework, which generated these resources; (2) a brief guide to help forest managers judge or initiate vulnerability assessments; (3) a "menu" of adaptation strategies and approaches that are directly relevant to forests of the Northeast and upper Midwest; (4) a second menu of adaptation strategies and approaches oriented to urban forests; (5) a workbook process with step-by-step instructions to assist land managers in developing on-the-ground climate adaptation tactics that address their management objectives; and (6) five real-world examples of how these resources have been used to develop adaptation tactics. The ideas, tools, and resources presented in the different chapters are intended to inform and support existing decisionmaking processes of multiple organizations with diverse management goals.

Quality Assurance

This publication conforms to the Northern Research Station's Quality Assurance Implementation Plan which requires technical and policy review for all scientific publications produced or funded by the Station. The process included a blind technical review by at least two reviewers, who were selected by the Assistant Director for Research and unknown to the author. This review policy promotes the Forest Service guiding principles of using the best scientific knowledge, striving for quality and excellence, maintaining high ethical and professional standards, and being responsible and accountable for what we do.

Cover Photo

A forest containing red pine and northern red oak trees. Photo by Maria Janowiak, U.S. Forest Service and Northern Institute of Applied Climate Science.

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CONTENTS

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INTRODUCTION

The second edition of *Forest Adaptation Resources: Climate Change Tools and Approaches for Land Managers*, like its predecessor, is intended to provide perspective, information, and tools to land managers considering how to adapt forest ecosystems to a changing climate. Broadly, adaptation includes all adjustments, both planned and spontaneous, in natural and human systems in response to climatic changes and subsequent effects (Parry et al. 2007). In this document, however, we focus on planned, ecosystem-based adaptation activities that use a range of strategies and approaches for sustainable management, conservation, and restoration of forests in order to maintain ecosystem integrity and provide environmental benefits to people.

In this document we present a set of interrelated chapters, each of which serves as a resource to help managers incorporate climate change considerations into management and devise adaptation tactics that can be used to respond to climate change (Fig. 1). These resources are designed to be used across a wide diversity of ecosystems, scales, and values. They do not make recommendations or set policy, but rather provide information, ideas, and processes for evaluating climate change as one component of management (Box 1).

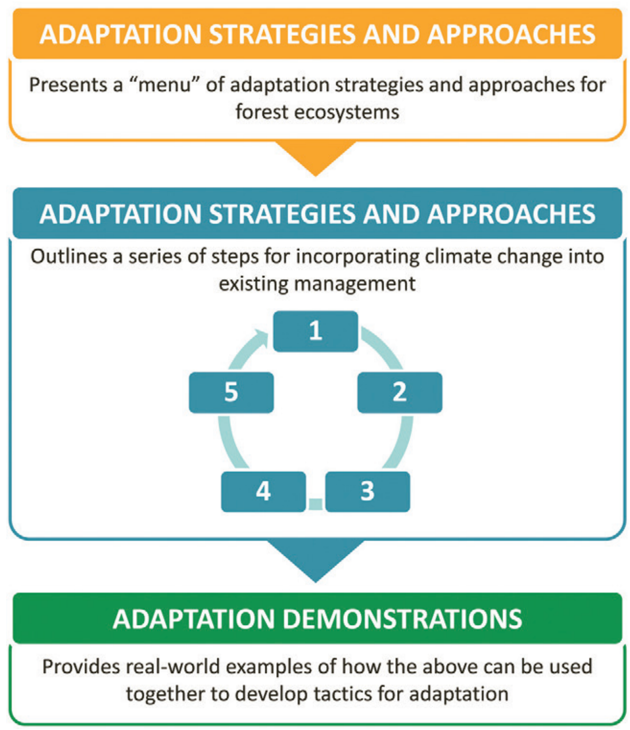


Figure 1.—Components of the Forest Adaptation Resources. The Adaptation Strategies and Approaches and the Adaptation Workbook can be used together to develop management tactics to adapt forests to the anticipated effects of climate change.

Chapter 1. Adapting to a Changing Climate: Overview of the Climate Change Response Framework describes the Climate Change Response Framework, summarizes the project components and subsequent outcomes, and provides a background for later chapters.

Chapter 2. Climate Change Vulnerability Assessments: a Brief Guide for Forest Managers is a guide for judging available vulnerability assessments, or even initiating a vulnerability assessment. Vulnerability assessments help users understand what ecosystem components may be at risk, which informs choices about adaptation.

Chapter 3. Adaptation Strategies and Approaches synthesizes a wide range of reports and peer-reviewed publications on climate change adaptation and provides a "menu" of adaptation actions that are relevant to the upper Midwest and Northeast. Expert feedback was used to further refine the synthesis of existing literature and provide examples of specific adaptation actions.

Chapter 4. Urban Forest Strategies and Approaches follows the same intent and format as Chapter 3, but is specific to the challenges and opportunities of managing forests in urban natural areas and developed sites.

Chapter 5. Adaptation Workbook outlines a process for incorporating climate change considerations into management planning and activities, while also complementing existing processes and procedures for making decisions. It uses a workbook approach to provide step-by-step instructions for land managers to translate the Adaptation Strategies and Approaches (Chapters 3 and 4) into on-the-ground management tactics that help forest ecosystems adapt to climate change.

Chapter 6. Adaptation Demonstrations provides real-world examples of how the Adaptation Strategies and Approaches and the Adaptation Workbook can be used together to develop adaptation tactics (Fig. 1).

Box 1

About the *Forest Adaptation Resources*

The *Forest Adaptation Resources* can:

- Help managers incorporate climate change considerations into management and devise adaptation actions that can be used to respond to climate change.
- Be used by a variety of land management organizations, including both private and public entities.
- Be approached, read, and used flexibly. Although arranged as a single document, the chapters are designed to both support each other and be used independently of each other.
- Be applied across multiple scales in different places, through
  - A broad framework for responding to climate change (Chapter 1)
  - A brief guide to considering climate change vulnerability assessments (Chapter 2)
  - A “menu” of many adaptation strategies and approaches for forest ecosystems (Chapters 3 and 4)
  - An Adaptation Workbook, which can be applied to a variety of ecosystems at multiple scales to help land managers integrate climate change considerations into management activities (Chapter 5).
- Describe practical applications of the process through “adaptation demonstrations” of how climate change was considered in real-world management situations using the other resources within this document (Chapter 6).

The resources in this document do not:

- Recommend management actions or policy.
- Replace institutional or legal processes. These resources are not intended to replace existing decisionmaking processes, but may augment them at an organization’s discretion.

CHAPTER 1. Adapting to a Changing Climate: Overview of the Climate Change Response Framework

As ecosystems continue to respond to the pressures of a changing climate, individuals and organizations tasked with managing these ecosystems will benefit from reexamining their priorities, objectives, and tactics. Some land managers may ultimately decide not to make any near-term changes in priorities or tactics, even after considering climate pressures on forests. Others may choose to accommodate forest change even as they attempt to ensure continued value from the ecosystem in question. In other words, as forests adapt naturally, organizations need to decide if they intend to play a role in adaptation through land management and how to play that role most effectively. This is easier said than done, of course, as land managers struggle to keep up with "traditional" challenges, not to mention the daunting complexities of climate change.

The U.S. Forest Service launched a community effort called the Climate Change Response Framework (CCRF) to address the major challenges that land managers face when considering how to integrate climate change into their planning and management. The *Forest Adaptation Resources* contains a description of the overall CCRF process in addition to specific tools used within the community. It is one of the major products of the CCRF, and both this edition and the first edition (Swanston and Janowiak 2012) have been shaped by broad community feedback and testing. This chapter describes the CCRF and how it is designed to address four substantial challenges commonly identified by forest managers.

The Climate Change Response Framework

The CCRF grew from the recognition that a focused effort was needed to compile and create climate impacts information relevant to resource management, and also to draw upon the collective experience of the forestry community to devise management responses to the changing climate. The Northern Institute of Applied Climate Science (NIACS) began this process in 2008 by providing climate change education, scoping activities, and discussion with land managers from across the upper Midwest and Northeast. The Chequamegon-Nicolet National Forest in Wisconsin was designated as a "test landscape" in 2009 as part of the CCRF pilot project (Swanston and Janowiak 2012), and its staff provided expertise, perspective, and a wide network of partners in northern Wisconsin to help create the CCRF. Four major issues were repeatedly raised in regionwide scoping discussions, and the means of addressing these issues became the core components of the emerging CCRF (Table 1).

The overall CCRF process is designed to continually incorporate new information, ideas, and lessons learned into the products and activities. It was conceived as a model for collaborative management and climate change response across large and diverse landscapes (Butler et al. 2011). In fact, the success of the initial pilot spurred expansion beyond Wisconsin to the Northwoods in 2010, the Central Hardwoods in 2011, the Central Appalachians in

Table 1.—Major adaptation issue or challenge repeatedly identified by natural resource managers, and corresponding component of the Climate Change Response Framework (CCRF)

Issue identified by managers	CCRF component addressing issue
Climate change is too big and too complex	**Partnerships**, which increase the capacity of organizations to cope with the overwhelming nature of the problem
Climate research is not relevant enough	**Vulnerability assessments**, which compile credible, relevant information about projected future climate conditions and forest responses and vulnerability
One-size-fits-all answers are insufficient	**Forest adaptation resources**, which help land managers and landowners devise adaptation actions to meet their objectives
There are not enough real-world examples	**Adaptation demonstrations**, which are on-the-ground examples of adaptation planning and implementation

2012, the Chicago Metropolitan Area and New England in 2013, and the Mid-Atlantic in 2014. These six CCRF ecoregional projects are designed to accommodate the natural distribution of ecosystems across the landscape and reflect how people organize themselves and interact with the ecosystems (Fig. 2).

The CCRF follows a basic process of engagement and activity (Fig. 3). With a region in mind, a critical step is to reach out to the people who live, work, and conduct research in the regional forests. These are the people who will ideally use CCRF products and can contribute critical information and perspectives

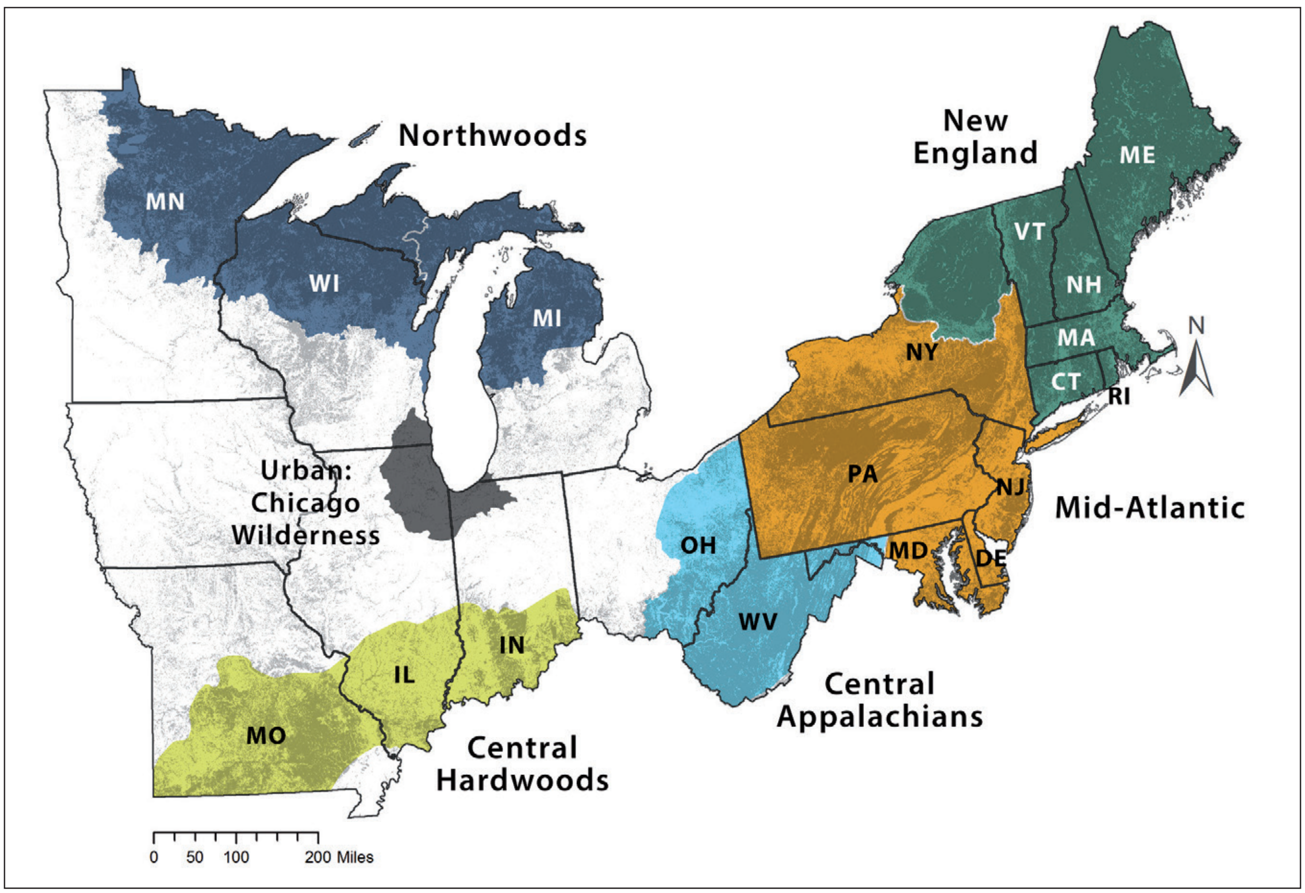


Figure 2.—Climate Change Response Framework ecoregional project areas.

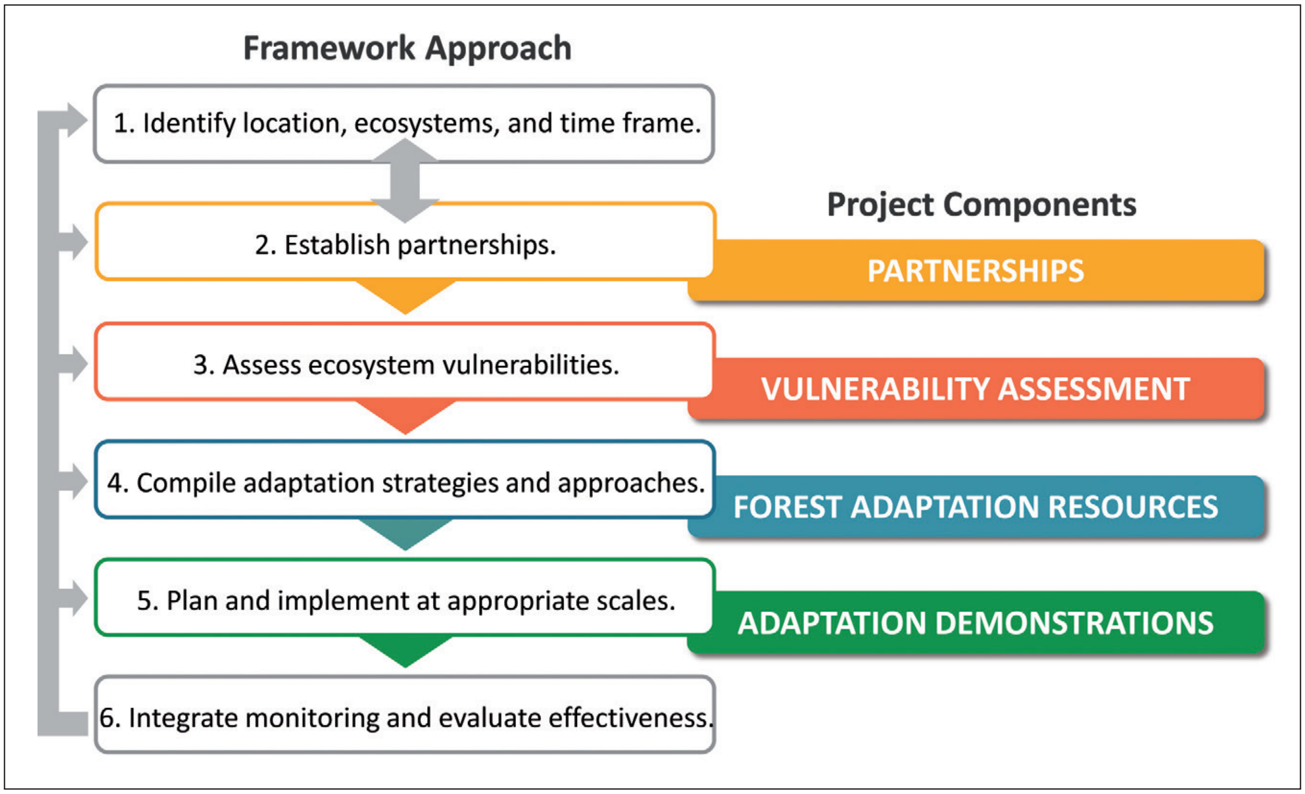


Figure 3.—Diagram of the iterative approach used by the Climate Change Response Framework to help natural resource professionals integrate climate change considerations into management planning and activities, and the resulting four project components.

to the creation of these products. Different groups may take part in all, or just some, aspects of the CCRF, depending on their skills, interests, and capacity. Many of these partners will collaborate to define critical forest ecosystems and assess their vulnerability to climate change. Likewise, regional partners are instrumental in compiling and considering adaptation strategies relevant to the places where they work and do research. Finally, the CCRF connects with partners willing to apply this information on their lands using the *Forest Adaptation Resources* to develop adaptation plans, and then share their stories of planning and implementation as adaptation demonstrations.

The CCRF process generates numerous products and activities, which are grouped into four major components: partnerships, vulnerability assessments, forest adaptation resources, and adaptation demonstrations. The character of each component can be tailored to individual regions or even ownerships. NIACS frequently evaluates the need for adjusting components based upon feedback from land managers in federal, state, tribal, nonprofit, and private organizations. In many ways, the grouping of products and activities into these components evolved in response to several issues that land managers consistently identified as key challenges in NIACS workshops and meetings. These issues—and the CCRF project components that address them—are described next.

"Climate change is too big and too complex"

Productive partnerships increase the capacity of organizations to cope with the overwhelming nature of climate change and ensure relevance, credibility, and usefulness of CCRF products.

Both individuals and organizations may be reluctant to address climate change directly because the issue is so complex and pervasive. Careful land stewardship already draws upon an enormous array of information and experience, including how climate has historically interacted with forest ecology and land management. At the same time, the potential for interaction of a range of plausible future climates with forest stressors, ecology, and management further magnifies the complexity of forest planning and decisionmaking. This added complexity can essentially be beyond the capacity of some organizations to integrate into their planning and operations, leading to an "uncertainty paralysis" in responding to climate change.

In coordinating the CCRF, NIACS reaches out to organizations and networks to learn about the people who live and work in a particular place, how they value and view their lands, and what skills and knowledge they might be willing to contribute to CCRF products and activities. By drawing upon the combined expertise, experience, and capacity of the broader forest sector and climate science communities, the CCRF can help meet climate-related needs of organizations and landowners while effectively reducing the burden on any single organization. This cross-ownership and cross-discipline collaboration also increases the overall rate of learning. Further, collaboration helps ensure that information generated by the community-based CCRF meets the needs of forest stewards in the region. The resulting partnerships within the CCRF are many and varied. For example, partners contribute expertise to vulnerability assessments, develop and review place-based adaptation strategies, serve as hosts and instructors at climate adaptation workshops, and share information about management goals and adaptation actions.

"Climate research is not relevant enough"

Forest vulnerability assessments created by the CCRF compile credible, relevant information about projected future climate conditions and forest responses and vulnerability.

Forest managers seeking to pursue science-based management often need to invest significant time sorting through a tremendous number of research publications on climate and its effects to find information that is credible, relevant, and understandable. They are frequently frustrated by the large spatial scales and long time frames of climate projections, which are typically much broader than those of forest planning and activities. Additionally, academic research uses an often bewildering assortment of climate scenarios, climate models, downscaling algorithms, time scales, and ecological models to project potential effects of climate change on forests. Many organizations simply cannot dedicate the time required to comprehensively review and synthesize this information, even if they have the multidisciplinary expertise.

The CCRF addresses this information challenge by creating a standardized series of forest ecosystem vulnerability assessments written specifically for land managers. Each assessment in the series is informed at the outset by regional experts, including both scientists and land managers. The series spans several ecoregions (Box 2) and uses the same suite of climate scenarios and models, vegetation impact models, and chapter templates (contemporary landscape, climate primer, past climate, climate projections, climate impacts, ecosystem vulnerability, and management implications). These assessments are place-based, meaning that information in the assessment about climate and ecology is rooted in the region, and interpreted and reviewed by regional experts. The actual assessment of ecosystem vulnerability takes place through a transparent consensus-building process with a panel of ecologists, modelers, and practitioners that work in the region (Brandt et al. 2016). The result is a highly credible product meeting the needs of many partners, but largely beyond the capacity of any single partner to create.

Box 2

Vulnerability Assessment and Synthesis Reports

NIACS has worked with the CCRF community to develop a series of ecosystem vulnerability assessments. We created a pilot assessment in northern Wisconsin and then applied lessons learned from that effort to create a standardized vulnerability assessment process and template. The objective of this assessment process is to determine vulnerability to climate change among forest community types within an ecological province (broad geographic areas that share climate, glacial history, and vegetation types). The assessment process uses a range of downscaled climate projections that are incorporated into dynamic and species distribution modeling to determine future habitat suitability of tree species. A comprehensive literature review provides a summary of the effects of climate change on disturbance processes, hydrology, and associated forest species in the area. A panel of experts then uses this information to assess climate change impacts on the drivers, stressors, and dominant species of forest communities in each ecoregion. These assessments are:

- *Central Hardwoods Ecosystem Vulnerability Assessment and Synthesis: a Report from the Central Hardwoods Climate Change Response Framework Project* (Brandt et al. 2014)
- *Chicago Wilderness Region Urban Forest Vulnerability Assessment and Synthesis* (Brandt et al., in review)
- *Mid-Atlantic Forest Ecosystem Vulnerability Assessment and Synthesis: a Report from the Mid-Atlantic Climate Change Response Framework Project* (Butler et al., in preparation)
- *Central Appalachians Forest Ecosystem Vulnerability Assessment and Synthesis: a Report from the Central Appalachians Climate Change Response Framework Project* (Butler et al. 2015)
- *Michigan Forest Ecosystem Vulnerability Assessment and Synthesis: a Report from the Northwoods Climate Change Response Framework Project* (Handler et al. 2014b)
- *Minnesota Forest Ecosystem Vulnerability Assessment and Synthesis: a Report from the Northwoods Climate Change Response Framework Project* (Handler et al. 2014a)
- *New England Forest Ecosystem Vulnerability Assessment and Synthesis: a Report from the New England Climate Change Response Framework Project* (Janowiak et al., in review)
- *Forest Ecosystem Vulnerability Assessment and Synthesis for Northern Wisconsin and Western Upper Michigan: a Report from the Northwoods Climate Change Response Framework Project* (Janowiak et al. 2014a)
- *Ecosystem Vulnerability Assessment and Synthesis: a Report from the Climate Change Response Framework Project in Northern Wisconsin* (Swanston et al. 2011)

"One-size-fits-all answers are insufficient"

The CCRF includes forest adaptation resources, with a menu of adaptation strategies and an adaptation workbook, to help land managers and landowners devise adaptation actions to meet their objectives.

Even with relevant and clarified information about climate change available, finding practical ways to consider and apply this information within existing decisionmaking processes, management practices, and operational constraints can be a considerable burden. This burden is made yet heavier by the expectation that there is a "right" way to pursue climate adaptation even as fundamental questions persist: What exactly is adaptation and how should its success be judged? Should adaptation occur through promotion of biodiversity or structural diversity? Does it require transition to nonnative species or abandonment of restoration goals? Is it compatible with existing forest planning? Does it require adoption of new management practices or goals? These and similar questions can make climate adaptation planning seem unrelated to current values, objectives, experience, and constraints, which typically drive the choice of on-the-ground actions. But it is critical that managers or landowners consider these questions when choosing adaptation actions, and the CCRF approach reflects the importance of doing so. The fundamental goal of the CCRF is to help landowners and managers identify acceptable ways to meet their own needs.

The CCRF Adaptation Workbook (Chapter 5) provides a structured process that draws upon broad-scale vulnerability assessment. A menu of strategies and approaches helps identify on-the-ground adaptation actions that tier to forest management goals. The strategies and approaches are the product of a synthesis of academic literature and widespread input from the forestry community. The Adaptation Workbook was developed as a practical adaptation planning tool. Users start with their management objectives, step down broad assessments to local scales, list opportunities and barriers to meeting management objectives given climate change, and then identify adaptation actions that increase the likelihood of meeting objectives. The Adaptation Workbook integrates consideration of climate pressures into management plans and activities while fundamentally grounding users in their original objectives, experience with local forests, and willingness to accept risk. In cases where meeting original objectives appears impractical or too high-risk, the user may decide to reconsider the original objectives. The result across a wide range of users is a diversity of approaches to climate adaptation linked to equally diverse values and objectives.

"There are not enough real-world examples"

The CCRF shares the stories of adaptation demonstrations, which are real-world examples of how land managers have considered ecosystem vulnerabilities and adaptation strategies in choosing actions to meet their management objectives.

The literature on climate adaptation has been expanding rapidly for several years, but much of it is still theoretical or principles-oriented in spite of a large demand for actual examples of on-the-ground forest adaptation. The interest in these adaptation demonstrations not only reflects the traditional desire of resource managers to see how a plan looks when implemented in an ecosystem, but also grows from their struggles with other climate-related challenges. Namely, the implementation actually integrates the various ways in which an organization or landowner dealt with all the challenges. Likewise, each adaptation demonstration illustrates the full process of the CCRF as it plays out in real-world examples of ecosystem management. To date, the CCRF has generated more than 185 on-the-ground examples of organizations using the menu of strategies and approaches with the Adaptation Workbook to plan and implement adaptation actions (Fig. 4). These examples represent a wide range of forest ecosystems and a variety of management goals and objectives.

The willingness of individual organizations to share their stories is a key aspect of partnership within the CCRF. The forest sector is on a steep learning curve with climate adaptation; the pressure to learn and adapt quickly will almost certainly grow through time. The current diversity of approaches to management, and of risk-tolerance levels, will probably lead to a comparable diversity of approaches to adaptation. Pursuing a diversity of approaches can be an excellent strategy for rapid learning by generating numerous examples of forest response across the landscape. Although the approaches may not be coordinated, sharing the intent and results of adaptation actions with the wider management community will help propel the rate of learning.

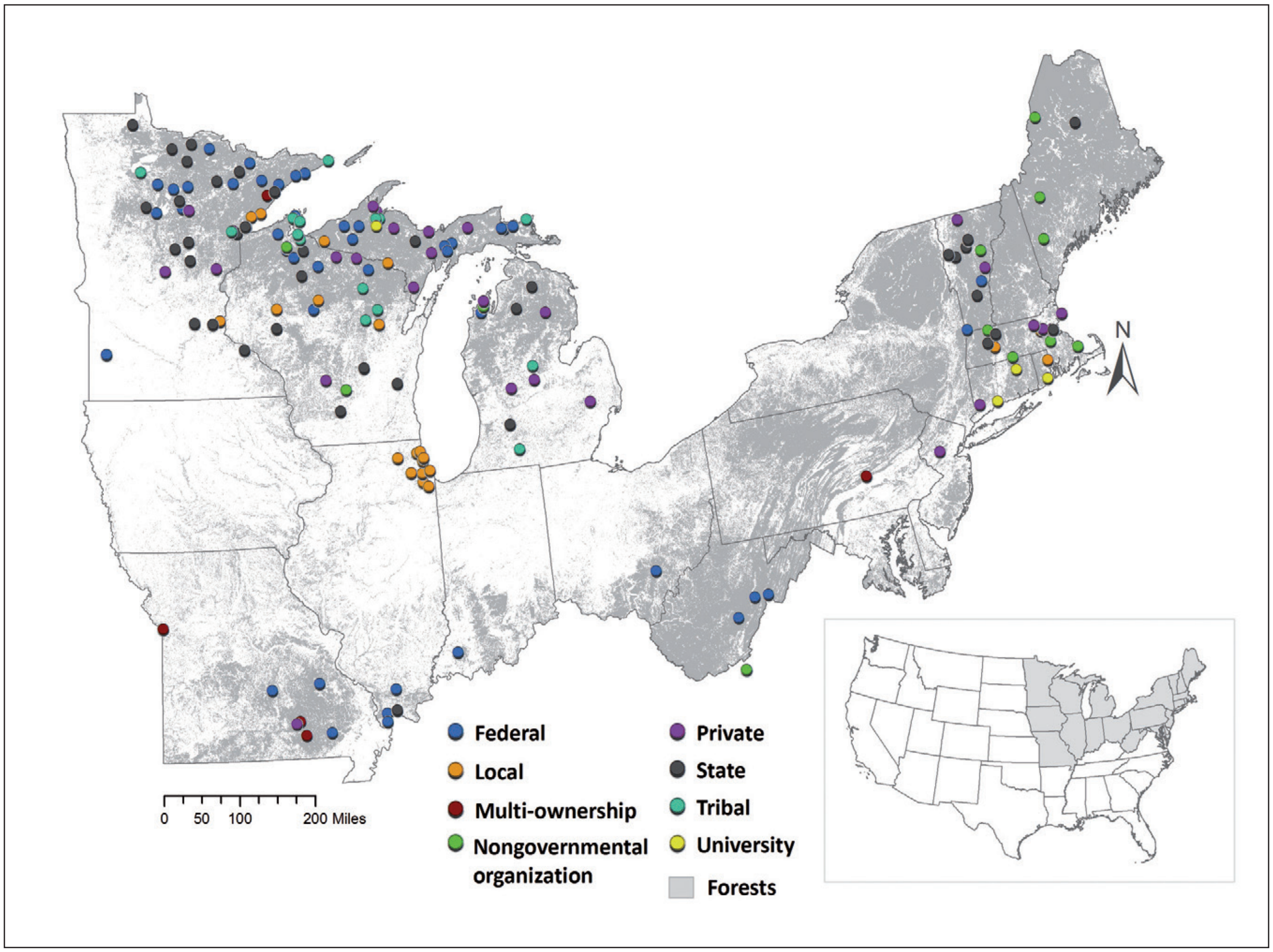


Figure 4.—Adaptation demonstration locations representing projects where natural resource managers used the Adaptation Workbook to integrate climate change considerations into their management.

Summary

The CCRF is a partnership-based approach for responding to climate change that was developed to help land managers cope with the challenges of integrating climate change considerations into land management. The CCRF groups its activities and products into four major components: partnerships, vulnerability assessment, forest adaptation resources, and adaptation demonstrations. It has grown over several years to cover the major forested areas of the upper Midwest and Northeast with more than 100 participating groups and many more individuals. As it has grown, the CCRF has also evolved to better meet the needs of partners, as well as integrate their ideas and experience. The CCRF has created numerous major products and compiled more real-world adaptation demonstrations than virtually any other single effort. The CCRF will continue to evolve as it works with yet more groups and ecosystems, but will continue its focus on meeting landowner needs and supporting diverse approaches to climate adaptation.

CHAPTER 2. Climate Change Vulnerability Assessments: a Brief Guide for Forest Managers

What is a vulnerability assessment? In the context of climate change and natural resource management, vulnerability assessments "synthesize and integrate scientific information, quantitative analyses, and expert-derived information in order to determine the degree to which specific resources, ecosystems, or other features of interest are susceptible to the effects of climate change, including climate variability and extremes" (Joyce and Janowiak 2011). Vulnerability assessments are essentially tools to help you identify what resources are at risk due to climate change, and why they are vulnerable to climate change (Glick et al. 2011). Vulnerability assessments can be important tools in adapting to a changing climate, but it is up to each individual decisionmaker to assess whether to prioritize the most at-risk resources, those at lowest risk, or some combination.

Vulnerability can be defined as the degree to which a system is susceptible to and unable to cope with adverse effects of climate change (Intergovernmental Panel on Climate Change [IPCC] 2007). Although many different definitions exist, most of the natural resource management community breaks down vulnerability into three main elements: exposure, sensitivity, and adaptive capacity (Glick et al. 2011, Stein et al. 2014). Exposure (the degree of stress on a system) and sensitivity (the degree to which a resource will be affected by that stress) are often combined into what is called potential impacts (Fig. 5). Potential impacts are the direct and indirect consequences of climate change on your resource. Adaptive capacity can be defined as the ability of a resource to accommodate or cope with potential climate change impacts with minimal disruption (IPCC 2007). Some people in the natural resource community focus on the biological or ecological aspects of adaptive capacity, whereas others broaden the definition to include human dimensions such as organizational capacity and economics (Glick et al. 2011, Nicotra et al. 2015).

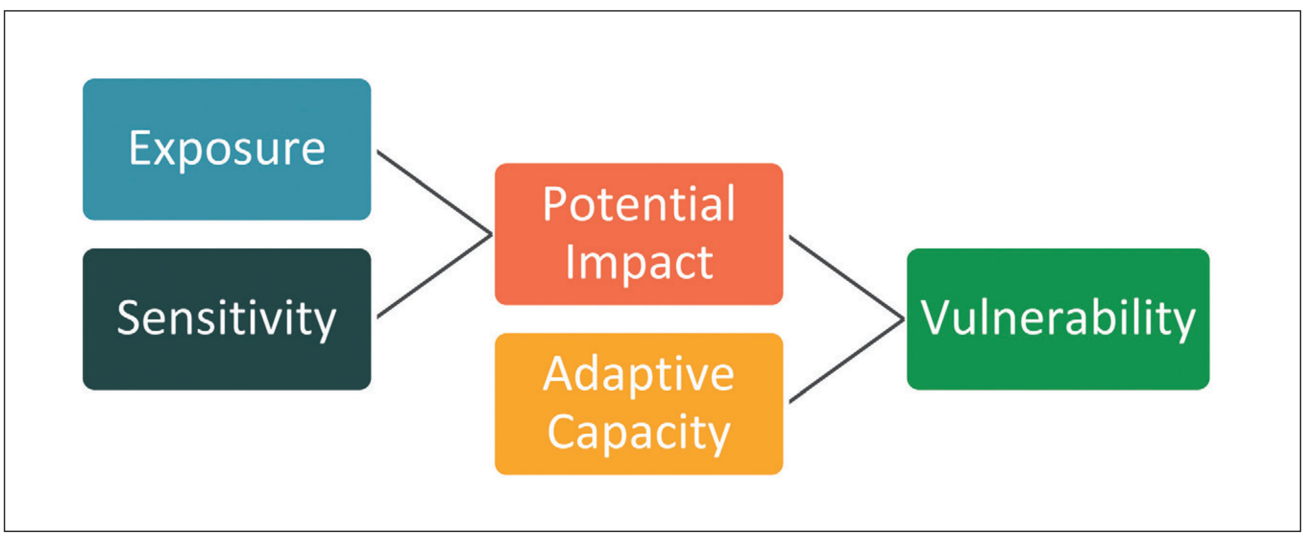


Figure 5.—The components of vulnerability. Modified from Glick et al. (2011).

Organizations are developing vulnerability assessments for a wide variety of purposes. The nature of the assessments undertaken depends largely on the types of management decisions they are intended to inform and the resource areas of focus. Some assessment frameworks are based on complex quantitative approaches that require specific expertise (Lexer and Seidel 2009, Nitschke and Innes 2008). Other frameworks use a numerical index approach (Comer et al. 2012, Manomet Center for Conservation Sciences and National Wildlife Federation 2013). Others are more qualitative in nature (Brandt et al. 2016).

Before undertaking a new vulnerability assessment, it is best to evaluate what information already exists and identify gaps that may need to be filled. Many assessments of climate change impacts and vulnerability have already been completed, and will probably cover many of your resources of interest. Then, you can decide whether it is worthwhile to undertake a new vulnerability assessment or just fill in a few gaps in an already prepared assessment or combination of documents.

This brief guide provides one approach to help forest managers evaluate existing vulnerability assessments. It also provides some tips if you choose to develop a new one. We highlight key components that make vulnerability assessments effective in informing management decisions using the best available science (see checklist on p.28). Many vulnerability assessments will be missing some of these components, so you may still need to decide what is most important for your purposes. We provide "do it yourself" (DIY) boxes throughout the chapter to help you evaluate an existing assessment or start your own if one is not available to meet your needs. For each step, we also offer examples of how we have approached each component in vulnerability assessments through the Climate Change Response Framework (CCRF; Chapter 1).

If you are starting a vulnerability assessment from scratch, this guide can also be a good launching point, but you may need additional resources. For additional guidance on developing assessments, as well as more examples of existing assessments, see *Scanning the Conservation Horizon: a Guide to Climate Change Vulnerability Assessment* by the National Wildlife Federation (NWF) (Glick et al. 2011). Also refer to Chapter 6 of NWF's *Climate-Smart Conservation: Putting Adaptation Principles into Practice* (Gross et al. 2014) and Chapter 2 of the Department of the Interior (DOI) Northeast Climate Science Center's *Integrating Climate Change into the State Wildlife Action Plans* (Staudinger et al. 2015).

Scope and Geographic Scale

Scope and Scale Checklist

The assessment:

- ☑ focuses on your resource of interest
- ☑ is at a geographic scale relevant to management of your resource

Why this is Important

Vulnerability assessments are meant to help inform decisions. Therefore, they are most effective if their scope covers the resources you are managing and their geographic scale is relevant to those resources.

Scope

Vulnerability assessments are developed for a variety of reasons. They can focus on individual species, ecological communities, water resources, infrastructure, specific industries, human populations, or a combination of topics. No vulnerability assessment will cover everything, so it is important to identify the scope that best suits specific management questions of interest. If you are undertaking a large project with multiple objectives that include vegetation, water resources, infrastructure, and recreation, you may need to rely on several assessments that focus on each of these areas to encompass the entire scope of your project (Box 3).

Geographic Scale

Once you have identified the appropriate scope, you will then need to figure out if the information is available at a scale that is appropriate for informing your decisions. This will partially depend on the scope of your issue and the questions you wish to answer. Several factors may limit the spatial resolution of vulnerability assessments, such as the resolution of past and projected climate data. Assessments that cover major regions of the country (e.g., the Midwest) or larger scales (e.g., the United States, North America) will probably be too broad to be useful for many on-the-ground forest management decisions. However, they can be helpful in finding relevant literature at finer scales and gaining a broad overview of likely climate change impacts. They can also be helpful for multi-state planning efforts, such as those led by Landscape Conservation Cooperatives. For most management and planning decisions, assessments that cover a state, ecoregion, or climatic zone and provide detailed information within that area are likely to be the most useful.

Box 3

DIY: Finding Vulnerability Assessments

Vulnerability assessments are becoming more common, but it can sometimes be difficult to track down assessments that are specific to your needs. Below are some vulnerability assessments that showcase many of the principles that are highlighted throughout this document:

- *Climate Change Vulnerability Assessment of Species of Concern in West Virginia* (Byers and Norris 2011)
- *A Climate Change Vulnerability Assessment for Focal Resources of the Sierra Nevada* (EcoAdapt 2014)
- *Assessing the Vulnerability of Watersheds to Climate Change: Results of National Forest Watershed Vulnerability Pilot Assessments* (Furniss et al. 2013)
- *Climate Change and Massachusetts Fish and Wildlife—Volume 2: Habitat and Species Vulnerability* (Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife 2010b)
- *A Climate Change Vulnerability Assessment for British Columbia's Managed Forests* (Morgan and Daust 2013)
- *Integrating Climate Change into the State Wildlife Action Plans, Chapter 2: Northeast and Midwest Regional Species and Habitats at Greatest Risk and Most Vulnerable to Climate Impacts* (Staudinger et al. 2015)
- *Ecosystem Vulnerability Assessment and Synthesis: a Report from the Climate Change Response Framework Project in Northern Wisconsin* (Swanston et al. 2011)

More examples can be found in the Related Resources section at forestadaptation.org, the Climate Registry for the Assessment of Vulnerability (nccwsc.usgs.gov/crave), and the virtual library at EcoAdapt's Climate Adaptation Knowledge Exchange (www.cakex.org). The vulnerability assessment literature is constantly evolving, so it is best to contact a local climate change expert for the latest scoop on vulnerability assessments that are being undertaken in your area.

Example: Scope and Scale

For vulnerability assessments associated with the Climate Change Response Framework, we focused on forest ecosystems and their dominant tree species (Box 2). We selected the scope of the assessment based on the needs expressed by the partners involved (state, federal, and nongovernmental organizations that focus on forest management) and available information. Early

Box 3 (continued)

project meetings delineated several perceived needs, including understanding changes in forest tree species, hydrology, and wildlife. Of those needs identified, we chose to focus first on changes in forest ecosystems and tree species because this was one of the areas of greatest need, and there were sufficient information and expertise available. We expect that further assessments (which we or others may develop) will help address the other information needs identified.

The scale of CCRF vulnerability assessments varied by region. In the Northwoods, we conducted individual assessments for each of three states within the Laurentian Mixed Forest Province (Handler et al. 2014a, 2014b; Janowiak et al. 2014a). In the Central Hardwoods (Brandt et al. 2014) and Central Appalachians (Butler et al. 2015), we did one assessment for several states within a single province. Both approaches to assessments provided information at the same resolution, however. Each approach had unique advantages. Conducting individual assessments for each state allowed us to tailor information specifically to that state and use classification systems that were the most familiar to people working within them. Combining assessment efforts across states was more cost-effective and ensured that a consistent classification system was used across states.

Core Assessment Team

Assessment Team Checklist

The assessment team has knowledge and expertise in:

- ☑ management of your resource of interest
- ☑ the social, biological, or physical science of your resource of interest
- ☑ the effects of climate change on your resource of interest
- ☑ the interaction of the above

Why this is Important

It is important that the information in vulnerability assessments is unbiased and clearly reflects the best available science. This is especially the case when vulnerability information is used in decisionmaking. Ideally, a team of experts undertakes vulnerability assessments that cover a range of disciplines relevant to the scope of the assessment.

Types of Expertise Needed

A vulnerability assessment team ideally consists of people who understand both resource management and the likely climate impacts on the biological, social, or physical drivers of a resource (Box 4). A well-rounded vulnerability assessment team will probably include several members from both the management and scientific communities. Managers from public, private, and nongovernmental organizations understand how decisions are made on the lands they manage and will be able to identify how climate change may affect these decisions. Scientists from universities, government agencies, and nongovernmental organizations are likely to have the best understanding of the latest scientific information that can inform the assessment. It is especially valuable for team members to have a good understanding of both science and management regarding your resource of interest and to be able to communicate those links.

The ideal team size will vary with the scope and scale of the project. Assessments that cover several resources and a large geographic area will require a larger team than those focused on a particular resource in a narrow geographic range. A good assessment will include at least one scientist and manager, and ideally, there will be several managers and scientists.

Box 4

DIY: Assembling Your Team

If you are starting a new vulnerability assessment, it can be a daunting task to figure out who should be involved in the process. A good place to start is by contacting a "boundary spanner" who works at the intersection of science and management. People in these positions are often connected to both the science and management communities, and will have a broad understanding of the expertise available in a region. The boundary spanner can work with you to identify scientists and managers who fit your needs. A few places to look for boundary spanners are:

- Cooperative Extension offices
- DOI Climate Science Centers
- DOI Landscape Conservation Cooperatives
- Habitat Joint Ventures
- Manomet Center for Conservation
- Joint Fire Science Consortia
- National Oceanic and Atmospheric Administration (NOAA) Regional Integrated Science Assessments
- The Nature Conservancy
- Northern Institute of Applied Climate Science
- U.S. Department of Agriculture (USDA) Climate Hubs
- U.S. Forest Service threat assessment centers
- Wildlife Conservation Society.

If you are still struggling to find the right people for your assessment team, you may need to do a broader search. One approach is to contact people who are lead authors on other assessments or publications that are relevant to your assessment. You can also make use of groups and discussion boards associated with Landscape Conservation Cooperatives, the directory on EcoAdapt's CAKE Web site, the community page on the Conservation Biology Institute's DataBasin Climate Data Center, Griffin Groups, and LinkedIn groups such as the Adaptability Climate Adaptation Network.

If team members need more training on how to conduct vulnerability assessments, several courses are available through the National Conservation Training Center (https://training.fws.gov).

Example: Assessment Teams

We assembled a small team of nine people for the northern Wisconsin vulnerability assessment, with equal representation from science, management, and technology transfer related to forests and climate change. We gradually expanded our teams to gain more diversity in management and science expertise as we moved forward with additional assessments, while still keeping assessment teams at a manageable size of about 15 to 25 people. In selecting team members, we sought representation from multiple organizations (e.g., national forests, state agencies, tribes, conservation organizations) and disciplines (e.g., fire ecology, forest pathology, and hydrology). Another consideration was to include a mix of generalists and specialists. We have found this expertise has been extremely beneficial in informing assessments.

Comprehensive Literature Review

Literature Review Checklist

The peer-reviewed and gray literature are reviewed and cited to describe:

- ☑ current conditions of your resource
- ☑ past changes in climate in your geographic area
- ☑ projected changes in climate in your geographic area
- ☑ projected impacts of climate change on your resource

Why this is Important

A comprehensive review of the peer-reviewed and gray literature can ensure that an assessment reflects the best available science. You will need this information to develop a clear synthesis of existing knowledge on the resource, determine the vulnerability of your resource, and evaluate uncertainty.

Peer-reviewed Literature

Peer-reviewed literature that is up-to-date and cited throughout will enhance the credibility of the statements made in an assessment. A comprehensive vulnerability assessment will include a literature review on the past changes, current conditions, and projected changes for your resource and past and projected changes in climate.

It is highly likely that other organizations have already developed literature reviews that address the impacts of climate change on your region. Some of these reviews will be published in scientific journals, and some will be in the gray literature (see next section).

When reviews are unavailable, or perhaps slightly out of date, scientific journals that focus on the science and management of your resource are an excellent source of information on current conditions and impacts. Scientific journals specializing in atmospheric sciences and climate can provide needed information on past and projected climate change.

If you must undertake a new literature review, most relevant peer-reviewed literature on these subjects can be found through interdisciplinary journal databases such as ISI Web of Knowledge (webofknowledge.com; requires subscription) or Google™ Scholar (scholar.google.com; free access). In addition, some tools have been designed specifically for finding peer-reviewed literature on climate change and forests. The Template for Assessing Climate Change Impacts and Management Options (TACCIMO; www.taccimo.sgcp.ncsu.edu) and the Climate Change Resource Center's Library (www.fs.usda.gov/ccrc) are two great resources. Because climate change science is constantly evolving, it is also helpful to set up electronic alerts for the latest articles (see Box 5).

Gray Literature

The gray literature can also play an important role in vulnerability assessments by adding technical, social, and policy information and social and policy context that may not be of academic interest but are nonetheless useful. Gray literature includes government reports, strategy documents, doctoral theses, white papers, conference proceedings, and pre-publication manuscripts that have not gone through a formal review and publication process. Vulnerability assessments themselves are often considered gray literature. These documents are often more recent than the peer-reviewed literature because they can be published more quickly and may only be available electronically.

The gray literature can be more difficult to find than peer-reviewed scientific publications. A Web search is sometimes the most effective method to find documents in this category, but requires careful filtering of irrelevant or unreliable information. In addition, a number of key Web sites post relevant gray literature specific to forests and climate change:

- The Products and Related Resources sections on the Climate Change Response Framework Web site provide links to literature and other sources specific to midwestern and northeastern forests (www.forestadaptation.org).
- The DOI Northeast Climate Science Center's library has a searchable database of both peer-reviewed and gray literature for the Midwest and Northeast (necsc.umass.edu/library).
- The U.S. Forest Service's Climate Change Resource Center contains a library with links to briefings, factsheets, Web sites, and government reports in addition to peer-reviewed literature (www.fs.usda.gov/ccrc).
- EcoAdapt's Climate Adaptation Knowledge Exchange Virtual Library provides links to peer-reviewed and gray literature related to climate change adaptation and vulnerability across a wide variety of sectors (www.cakex.org/virtual-library).
- The Climate Registry for the Assessment of Vulnerability is a community resource that houses information on assessments of the vulnerability of various natural and human resources to a changing climate (https://nccwsc.usgs.gov/crave).

The scientific and gray literature is constantly evolving, but several key documents may be particularly helpful to a broad range of natural resource managers in the Midwest and Northeast:

- Documents associated with the National Climate Assessment
    - *Climate Change Impacts in the United States: the Third National Climate Assessment* (Melillo et al. 2014)
    - *Effects of Climatic Variability and Change on Forest Ecosystems: a Comprehensive Science Synthesis for the U.S. Forest Sector* (Vose et al. 2012)
    - *Impacts of Climate Change on Biodiversity, Ecosystems, and Ecosystem Services: Technical Input to the 2013 National Climate Assessment* (Staudinger et al. 2012)
    - Regional technical input reports
        - *Climate Change in the Midwest: a Synthesis Report for the National Climate Assessment* (Hatfield et al. 2014)
        - *Northeast* (Horton et al. 2014).
- USDA Climate Hubs regional vulnerability assessments
    - *Northeast and Northern Forests Regional Climate Hub Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies* (Tobin et al. 2015)
    - *USDA Midwest and Northern Forests Regional Climate Hub: Assessment of Climate Change Vulnerability and Adaptation and Mitigation Strategies* (Hatfield et al. 2015).

Box 5

DIY: Keeping Up with New Information

Keeping current on a subject as broad and rapidly evolving as climate change can seem overwhelming. But there are simple things you can do to make your life easier.

1. Subscribe to newsletters. Several organizations are tracking the literature so you don't have to. The Northern Institute of Applied Climate Science and the Northeast Climate Science Center deliver regular newsletters that are focused on climate change science delivery for land managers in the Midwest and Northeast. Other national newsletters like ClimateWire can also be helpful in discovering new literature.
2. Set up email alerts. Many journal databases such as Web of Knowledge have a feature that allows you to receive an email alert when articles you select are cited or when new articles show up in a saved search. For general Web searches, Google Alerts performs a similar function. For example, you could set up an email alert for a search on "climate change," "forests," and "Illinois." You can easily set up a free Google alert here: https://www.google.com/alerts.
3. Subscribe to RSS feeds on your favorite Web sites. RSS stands for Really Simple Syndication. It allows you to regularly gather information from Web sites without actually visiting them by delivering the information to your computer as a "feed." Web sites like the Climate Change Resource Center will often post the latest publications and tools relevant to forests and climate change. You can find out what's new by subscribing to an RSS feed. You can learn more about RSS feeds and how to set them up at www.fs.fed.us/ccrc/whatis_rss.shtml.
4. Subscribe to Twitter feeds. Twitter is rapidly becoming a reliable source for learning about the latest scientific discoveries. You can follow scientific organizations that are doing work on climate change and forests. You can find out more about Twitter at https://about.twitter.com/. Organizations to follow include:
    - Government agencies that focus on climate change, natural resources research, or both (U.S. Geological Survey, U.S. Forest Service Research and Development, U.S. Global Change Research Program)
    - Popular and scientific publications (Science Magazine, Nature, Scientific American)
    - Organizations specifically focused on climate change communication (ClimateCentral, ClimateCommunication, Climate Reality).

    Alternatively, you can search for hashtags related to your subjects of interest, such as #climatechange, #adaptation, #climate, and #forest.

If you take these steps, you're likely to be on top of the majority of the literature relevant to your assessment!

Example: Literature Review

We reviewed a combination of peer-reviewed and gray literature in all of the vulnerability assessments undertaken for the Climate Change Response Framework. We started by reviewing relevant synthesis documents that covered our geographic areas, such as state forest assessments, regional ecological assessments, and regional climate change assessments. We also did primary literature searches using Web of Knowledge and Google Scholar. We searched for keyword combinations of climate change and topics of interest such as fire, invasive species, and specific forest community types. We further filtered by geography using keywords such as state names, ecological region names, or geographic regions like "Midwest" or "Appalachians." In addition to searches specific to climate change, we searched for articles pertaining to the general ecology, management, and climate of each region and climate-related keywords such as temperature, precipitation, snow, and tornadoes. We further supplemented these searches with "snowball searches," where we found articles that cited or were cited by the articles we found. This method turned up hundreds of articles that were topically and geographically relevant to the assessment. Members of the core assessment team and other contributors also recommended helpful references during the revision process. We then used a citation manager (EndNote®; Thomson Reuters, Philadelphia, PA; www.endnote.com) to organize literature and links to digital versions of these publications and added more keywords and groupings for easier sorting.

Observed Trends and Future Projections

Trends and Projections Checklist

The assessment evaluates trends in:

☑ the climate of your assessment area

☑ your resource of interest

The assessment evaluates projections of:

☑ the climate of your assessment area across a range of possible futures

☑ your resource of interest across a range of possible futures

Why this is Important

If you do not understand past and projected climate changes in your area, you cannot accurately assess the vulnerability of your resources to climate change. An understanding of changes in climate in the recent and more distant past can help you understand how your resource has responded to previous shifts in climate. Examining a range of projected future changes, or an average projection along with a statistical confidence estimate, will allow you to understand where projections offer more or less certainty. Trends and projections are the most useful if they are regionally specific and at a resolution sufficient for informing management decisions.

Trends in Climate

Although vulnerability assessments often focus on future projected changes, understanding past change provides an important historical context and can help you understand whether your resource may already be experiencing impacts from a changing climate. It is helpful to evaluate past changes in climate over multiple decades in the historical record to give the clearest indication of past change. Many decades of data (30 or more years) need to be analyzed in order to detect trends in temperature and precipitation because climate is a long-term average. It is also helpful if trends are evaluated with multiple starting dates to avoid bias. For example, examining changes in temperature since the 1970s could overestimate the rate of change in an area because the 1970s were cooler than the long-term average across the United States, and starting in the 1930s could underestimate the rate of change because that period was warmer than the long-term average in many parts of the United States. A good assessment will present the information in an unbiased way across the entire historical record, using maps and graphs to show spatial and temporal variation. It is important to note that future conditions may have no historical analog. Therefore, although the past is informative for understanding how much change has occurred already, the future changes may be on a different trajectory.

Future Climate Projections

Global climate models—mathematical representations of the physical, biological, and chemical processes that control Earth's climate—can help us project the future. Just as with past trends, it is more informative to evaluate future projections of climate over multiple decades. How far to project climate into the future will depend on the resources evaluated and the types of decisions for which the assessment will be used. For long-lasting infrastructure like bridges, a 100-year time horizon can be helpful. For short-lived organisms or infrastructure that needs to be replaced more frequently, a shorter time horizon (30–50 years) will often be sufficient. For long-lived organisms like trees, it may be helpful to use projections for both the short and long term, to encompass both short-term management actions and long-term growth.

It is important that assessments include some estimate of the variation and uncertainty in climate change projections. One approach is to apply a range of possible futures by using multiple models and greenhouse gas emissions scenarios. Another is to calculate a probability distribution or confidence range around a mean.

Global climate models operate at spatial resolutions that are much too coarse for most decisionmaking needs. Therefore, they are often downscaled to a geographic scale that is more useful. Experts from a variety of organizations have developed downscaled climate datasets that are available free online (see Box 6). Each uses slightly different techniques at slightly different spatial and temporal scales. If you are unfamiliar with climate models, greenhouse gas emissions scenarios, and downscaling, *Climate Projections FAQ* (Daniels et al. 2012) can be a helpful resource. It is important to keep in mind, however, that even though downscaled climate data may be helpful, the additional step in data processing can add biases and uncertainty to your estimates.

Box 6

DIY: Finding and Using Climate Data

Whether you intend to supplement an existing vulnerability assessment or start one from scratch, finding climate data to suit your needs can be challenging. When possible, it's best to consult with experts in climate science, such as staff at DOI Climate Science Centers and the NOAA Regional Integrated Science and Assessments program. Below are a few sources we have found useful that you can select based on your experience and comfort level.

Novice: Use these sources when you have minimal or no experience working with geographic information systems (GIS), you are new to climate data, or you need a quick snapshot of projections and trends. These resources provide mapped trends and projections that you can view on the Web:

- The U.S. Geological Survey (USGS) National Climate Change Viewer includes downscaled historical and future climate projections from the most recent IPCC assessment report, the Fifth Assessment Report (www.usgs.gov/climate_landuse/clu_rd/nccv.asp).
- ClimateWizard, developed by The Nature Conservancy, the University of Washington, and the University of Southern Mississippi, is a user-friendly Web-based map viewer of downscaled past and projected climate change from the IPCC Fourth Assessment (www.climatewizard.org).
- University of Wisconsin's Center for Climatic Research offers statistically downscaled climate projections from the IPCC Fourth Assessment for the eastern United States, which includes snowfall and extreme weather events (http://nelson.wisc.edu/ccr/resources/visualization-and-tools.php).

Expert: Use these when you have advanced skills in GIS, statistical analysis, or processing spatial and temporal data, or you require specific data as inputs into impact models:

- The PRISM Climate Group provides downloadable gridded historical climate data from 1895 to present for the continental U.S. (prism.oregonstate.edu).
- NOAA's Climate Data Online provides free access to the archive of global historical weather and climate data collected by the National Centers for Environmental Information (formerly the National Climatic Data Center) (ncdc.noaa.gov/cdo-web/).
- The USGS Geo Data Portal project provides scientists and environmental resource managers access to downscaled climate projections and other data resources that are otherwise difficult to access and manipulate (cida.usgs.gov/gdp).

Box 6 (continued)

Example: Climate Trends and Projections

When undertaking vulnerability assessments for the Climate Change Response Framework, we were confronted with many potential options for information on climate trends and projections. We narrowed down potential options based on the need for consistency across the geographic areas where we were working, the needs of the impact modelers with whom we were working, the need to show a range of models and emissions scenarios, and how easily we could access and use the data. For past climate trends and baseline data, we relied on the ClimateWizard Custom tool (which is no longer available; Girvetz et al. 2009). This tool used a gridded historical dataset (PRISM; Gibson et al. 2002) and allowed us to visualize changes over space and time. It also provided us with a measure of statistical confidence for observed trends. We examined linear trends in annual, seasonal, and monthly mean, maximum, and minimum temperature and total precipitation, beginning in 1901, 1951, and 1971 through the present. We reported the information both temporally and spatially, and also reported which trends were statistically significant.

For future climate projections, we chose downscaled climate data that were made available on the USGS Geo Data Portal (Stoner et al. 2012). This dataset provided a consistent source of future climate projections for all of our vulnerability assessments. This dataset operates on daily time steps, has a good range of climate models and emissions scenarios, and a long time horizon. However, it lacked solar radiation projections needed for some impact models and had a steep learning curve. We chose two climate model–scenario combinations to give a range of possible futures that were used as inputs into all of the forest impact models. For a high end of the range, we chose a climate model that was relatively sensitive to greenhouse gas changes, GFDL (Delworth et al. 2006), coupled with a scenario that projects a large increase in greenhouse gas emissions, A1FI. At the lower end of the range, we chose a climate model that was less sensitive to greenhouse gas changes, PCM (Washington et al. 2000), coupled with a scenario that projects a stabilization and decline in greenhouse gas emissions, B1. We expressed changes in future annual and seasonal mean, maximum, and minimum temperature and total precipitation as the difference between a projected 30-year average (2010–2039, 2040–2069, and 2070–2099) and the average for the last 30 years of the 20th century. We expressed uncertainty by showing the range of future projections both spatially and over time.

Trends in Your Resource

It is also helpful if an assessment examines observed changes in your resource of interest. Although these changes may not directly relate to climate, it can help you determine if your resource is already experiencing adverse impacts that may be affected by changes in climate. For example, if an assessment focuses on coldwater fish, long-term monitoring data on fish populations and stream temperature would be very helpful. Often, however, long-term monitoring data are patchy, unavailable, or difficult to interpret for trends. Therefore, trends in your resource can be considered an added bonus rather than an absolute requirement. When an assessment lacks long-term monitoring trends, local knowledge and expertise from managers or traditional ecological knowledge can help you fill information gaps.

Projected Impacts on Your Resource

When available, models that specifically address the impacts of climate change on your resource of interest can be extremely useful. Impact models generally come in two main categories: statistical models and process models. Statistical models use observed data to determine relationships between climate and other factors and the distribution or behavior of a resource. Researchers can then predict future distributions based on these relationships and future climate projections. Process models use mathematical representations of physical, biological, or social processes to simulate changes in the resource in the future. Both approaches can be useful. Statistical models are less computationally intensive, so this approach can usually be applied to more resources (e.g., more species or more habitats), more climate scenarios, or larger areas. Process models can provide additional information on migration, disturbances, management, or interactions among multiple factors, but are more computationally intensive and thus usually limited to smaller areas or fewer resources. Not all vulnerability assessments will have impact model projections, but when they do, projections will ideally be transparent about their degree of certainty. This can be expressed as a range of climate models and emissions scenarios or as an average with a probability distribution or other confidence measure. In addition, impact model projections are most useful when their time frames are in line with the planning horizon of that resource.

Example: Forest Trends and Projections

We derived baseline data and observed trends in forest resources in each of our six Climate Change Response Framework vulnerability assessments from data collected by the U.S. Forest Service's Forest Inventory and Analysis (FIA) program (U.S. Forest Service 2015). This monitoring program goes through strict quality control and uses a consistent methodology across the country, ensuring that comparisons can be made over space and time.

Many impact models are available to project the impacts of climate change on forest ecosystems. Our approach to incorporating impact model results into CCRF vulnerability assessments was to focus on models that could provide consistency across all five vulnerability assessments while examining projected changes from a variety of approaches. We relied upon the Climate Change Tree Atlas as a statistical model because it covered the entire eastern United States, it was based on FIA data, and results were already available for more than 100 tree species (Iverson et al. 2008, Landscape Change Research Group 2014). We used LANDIS-II (Duveneck et al. 2014, Scheller et al. 2007) or LANDIS Pro (Wang et al. 2013) as process models. We chose these models because data were available over large areas that lined up within our assessment areas, and they provided a useful contrast to the Tree Atlas in simulating movement and growth of species over time. In some assessments, we made use of the PnET-CN (Aber et al. 1997, Peters et al. 2013) or LINKAGES-II (Wullschleger et al. 2003) models as additional forest process models to understand ecosystem responses to climate change such as nutrient cycling and ecosystem productivity. We also used results from the VIC model, a hydrologic model, to understand how climate change may affect soil moisture, evapotranspiration, streamflow, and runoff for some assessment areas when data were available. All modeling teams used the same set of climate projections as input data. In all cases, the main factors that we considered when deciding whether to use a model were the usefulness of the results in informing decisions, confidence in the quality of the information, availability of willing scientific collaborators, and spatial coverage.

Vulnerability Determinations

Vulnerability Elements Checklist

The assessment qualitatively or quantitatively determines vulnerability of my resource. Most vulnerability assessments will include these main components:

☑ Potential impacts
- Exposure
- Sensitivity

☑ Adaptive capacity

Why this is Important

Many vulnerability assessments rank or prioritize vulnerability by using various methods (e.g., indices, decision trees, expert consensus, or mathematical models). Regardless of the method used, being explicit about what makes a resource vulnerable will help managers identify actions they can take to reduce vulnerability.

Potential Impacts

Good assessments will clearly delineate potential impacts on your resources of interest, either separately as exposure and sensitivity elements, or combined.

Exposure

Exposure is the sum of climate and climate-related changes that may affect your resource. These changes could be a stressor for your resource, be beneficial to your resource, or not influence your resource at all. When evaluating exposure, good assessments will consider the suite of direct and indirect changes that may occur in the area where your resource is located. Ideally, the assessments will help you understand how multiple changes may interact or build on each other. This can include exacerbation of current stressors or changes in ecological drivers to your ecosystem.

Below are examples of exposure factors you may wish to consider, ranging from more direct to more indirect:

- Temperature: means, seasonal patterns, temperature extremes, growing season length
- Precipitation: annual and seasonal totals, heavy rain events, type of precipitation (rain vs. snow)
- Drought: frequency, length, or spatial extent
- Wind disturbance: frequency, severity, type
- Winter conditions: snow depth, duration of snow cover, soil freeze/thaw
- Hydrologic changes: soil moisture, streamflow, flood duration and depth, runoff
- Fire: frequency, severity, and seasonality

Sensitivity

Sensitivity is a measure of how responsive a resource is to changes in climate. Sensitivity includes how much a species, ecosystem, or built structure may respond to exposure to changes (such as the factors listed above). This response could be negative or positive, depending on the resource or the type of exposure factors considered. Negative sensitivity responses could occur if exposure exceeds a threshold where a species is no longer able to survive or reproduce. Positive sensitivity responses could result if the growth rate or number of reproductive cycles of a species increases with longer growing seasons and milder temperatures.

Below are examples of sensitivity factors:

- Sensitivity of the phenology of plants and pollinators to warmer springs or falls
- The degree to which growth or reproductive rates of species are helped or hindered by increased temperature or changes in precipitation
- Susceptibility of roads to erosion from heavy rains or buckling under extreme heat

Putting it Together

Many vulnerability assessments will combine exposure and sensitivity into an overall estimate of potential impacts. When available, quantitative approaches using impact models can be extremely useful for assessing potential impacts. Impact models generally combine mathematical representations of exposure and sensitivity into a statistical or simulation model in order to project the likely changes in that resource in the future. They may combine elements of exposure such as changes in seasonal temperature, growing season length, and precipitation with elements of sensitivity such as a species' metabolic or photosynthetic rate.

However, no impact model can possibly include a comprehensive analysis of all elements of exposure or sensitivity. For example, most impact models do not account for interactions among multiple disturbances that are likely to affect ecosystems, such as insect outbreaks, wildfire, and flooding. Therefore, additional qualitative or semiquantitative analyses of impacts, such as expert judgment or vulnerability indices, are needed to account for these factors. The analysis could be something as simple as rating the impacts on a scale from very positive to very negative, or a more complex rating system with multiple factors. Some examples include NatureServe's Climate Change Vulnerability Index (Young et al. 2010) or the U.S. Forest Service System for Assessing Vulnerability of Species (SAVS; Bagne et al. 2011). For habitats, the NEAFWA Habitat Vulnerability Assessment Model (Manomet Center for Conservation Sciences and NWF 2013) or NatureServe's Habitat Climate Change Vulnerability Index (Comer et al. 2012) are good examples. For some resources, no quantitative impact models will be available, and all evaluations of exposure and sensitivity will rely on a qualitative approach.

Adaptive Capacity

Different disciplines, even within the natural resource management community, define adaptive capacity differently. In assessments that focus primarily on species or ecosystems, adaptive capacity is often characterized by biological or ecological characteristics that would allow a species or system to respond to change, such as the diversity of genotypes, species, or age classes, or the ability to tolerate large-scale disturbances (Beever et al. 2015, Nicotra et al. 2015). However, in assessments that focus primarily on social factors like the tourism industry, adaptive capacity may include things like wealth or organizational capacity. Organizational adaptive capacity can also be applied to managers' ability to respond (Klausmeyer et al. 2011). Adaptive capacity can mean different things to different people, so it is helpful if the assessment provides a clear definition. Quantitative models that evaluate adaptive capacity are rare; therefore adaptive capacity is often evaluated by using a numerical score or qualitative ranking (e.g., high, medium, low).

Overall Vulnerability

Impacts and adaptive capacity are often evaluated separately and then combined into an overall assessment of vulnerability. Because most quantitative models do not include an assessment of adaptive capacity, most determinations of vulnerability will be index-based or qualitative, such as those described in Box 7. In an index-based assessment, for example, low sensitivity to flooding might receive a score of 1 while high sensitivity to flooding might receive a score of 3. Similar scores are assigned for sensitivity to other factors, for exposure, and for adaptive capacity, and then summed or averaged. Another approach is to use more qualitative rankings of high, medium, or low impacts and adaptive capacity based on an overall impression of how different factors may influence a resource. Regardless of the method chosen, good assessments will describe the information that was considered in the final determination of vulnerability for that resource in a way that is transparent to the reader.

Box 7

DIY: Vulnerability Determination Methods

Many researchers have developed methods for evaluating the components of vulnerability, so you don't have to create your own method from scratch. Below are examples of methods being used by various groups to determine overall vulnerability.

If you are assessing the vulnerability of species:

- The NatureServe Climate Change Vulnerability Index is one of the most widely used tools for assessing the vulnerability of plant and animal species (Young et al. 2010).
- The System for Assessing Vulnerability of Species was developed by U.S. Forest Service researchers to specifically address the vulnerability of terrestrial vertebrate species (Bagne et al. 2011).
- The Forest Tree Genetic Risk Assessment System was developed by North Carolina State University and the U.S. Forest Service specifically for tree species (Devine et al. 2012).

If you are assessing the vulnerability of ecosystems or habitats:

- The NatureServe Habitat Climate Change Vulnerability Index is a companion to NatureServe's species index and was recently applied to the desert Southwest (Comer et al. 2012).
- The NEAFWA (Northeastern Association of Fish and Wildlife Agencies) Model was developed by the Manomet Center for Conservation Sciences to assess habitat vulnerability in the Northeast (Manomet Center for Conservation Sciences and NWF 2013).
- The process developed for the Climate Change Response Framework (see the following example) can be applied to a variety of forest types and natural communities.

Example: Vulnerability Determination

In our recent series of vulnerability assessments for the Climate Change Response Framework, we developed a consistent process for assessing vulnerability using a panel of experts who formed our assessment team (Brandt et al. 2016). For each assessment, we organized a panel of about 20 scientists and managers. This group met in person to assess the vulnerability of forest systems in the assessment area to climate change over the next century.

At the beginning of the meeting, the panel received a series of introductory presentations on observed and projected climate, as well as impact model results (Fig. 6). This helped to ensure that all panelists were operating with the same understanding of the range of potential impacts on forest ecosystems. The panel then assessed the potential impacts for individual forest systems based on the presented information coupled with their own expertise. We asked the panelists to consider the important drivers, dominant species, and stressors for each forest system. Impacts on drivers were considered positive if they would alter system drivers (e.g., fire regime, soil moisture) in a way that would be more favorable for that community type, or negative if they would create less favorable conditions for that community type. Impacts on stressors were considered negative if they increased the influence of that stressor (e.g., invasive species, pathogens) on the community type, or positive if they decreased the influence of that stressor on the community type.

Panelists also assessed adaptive capacity based on their knowledge of the community types in the assessment area. The panel focused on these factors: whether dominant species had high dispersal ability; the species, functional, and genetic diversity of the community; and the ability of the community to tolerate or recover from a wide variety of disturbances. The panelists were directed to base these characteristics on the current condition of the system, given past and current management regimes, and with no consideration of potential management changes (adaptation) that could influence future adaptive capacity.

Box 7 (continued)

Panelists were directed to mark their rating of each vulnerability component in two-dimensional space on an individual worksheet and on a group poster (Fig. 7). Individual ratings were discussed to arrive at a group determination. In many cases, the group determination was at or near the mean of all individual determinations. However, sometimes the group determination deviated from the mean because further discussion caused some group members to alter their original response.

This approach to evaluating vulnerability was flexible enough to be used across multiple community types, ecoregions, and classification systems and easy for panelists to learn. The individual determinations by each expert also helped gauge the level of consensus on the vulnerability of a system. Finally, it gave decisionmakers what they were looking for: a ranking of relative vulnerability.

Figure 6.—Expert panel discussion of forest vulnerability. Photo by Leslie Brandt, U.S. Forest Service.

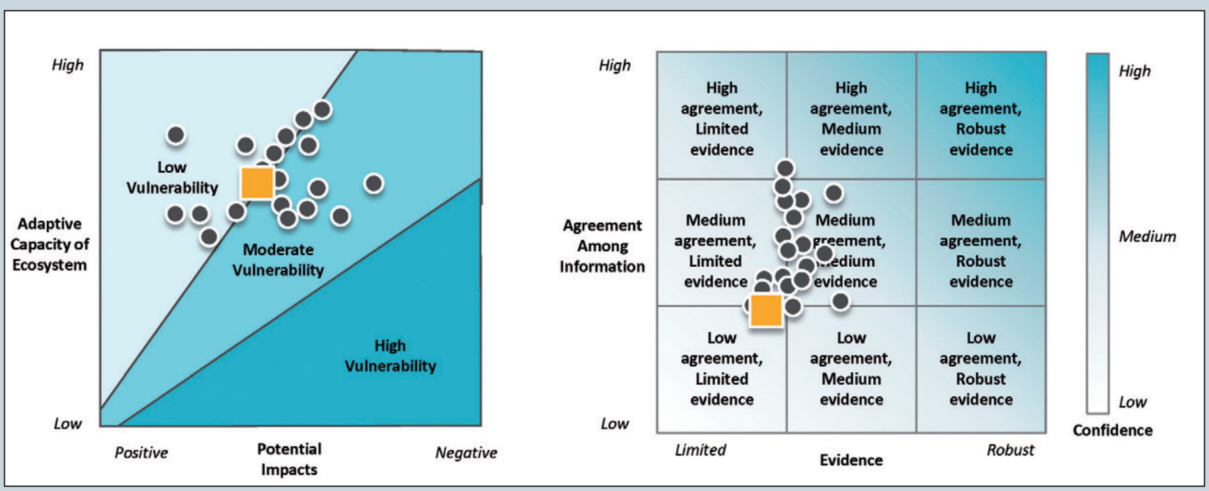


Figure 7.—Example vulnerability determination for a forest ecosystem during a vulnerability assessment conducted through the Climate Change Response Framework. Each expert panelist provides an individual determination of ecosystem vulnerability (circles). The group then comes to a consensus on vulnerability through discussion (square).

Evaluating Uncertainty

Uncertainty Checklist

The assessment qualitatively or quantitatively evaluates the uncertainty of:

- ☑ projected changes in climate
- ☑ projected impacts on your resource
- ☑ the vulnerability of your resource to climate change

Why this is Important

If you are going to adjust management decisions in light of projected changes in climate, you want to have some confidence that change is likely to occur. Unfortunately, the future is never certain, and managers need to make decisions even when there is high uncertainty. Explicitly stating the relative level of certainty about projected impacts, adaptive capacity, and overall vulnerability can help decisionmakers identify those areas where there is higher confidence that an outcome is likely to occur. This can be useful for identifying areas of focus for further research and for helping decisionmakers gauge the level of risk they are willing to take. Uncertainty can be described in qualitative terms, quantitative terms, or a combination thereof (see Box 8).

Quantitative Uncertainty

Quantitative measures of uncertainty can include the probability of an event occurring or standard deviations around a mean. Sometimes, quantitative probabilities are translated into a verbal description of likelihood, such as the likelihood scale that the IPCC uses (Fig. 8). For assessments or components of assessments that rely primarily on quantitative information, such as observational data, statistical models, and simulations, it may be possible to convey a quantitative measure of uncertainty. Quantitative estimates of uncertainty can also be made by conducting formal surveys of experts.

Qualitative Uncertainty

Qualitative measures of uncertainty are often necessary for vulnerability assessments due to the lack of quantitative estimates of many vulnerability components, such as adaptive capacity. Qualitative estimates of uncertainty can include an evaluation of the extent of evidence and the amount of agreement among that evidence, such as the confidence scale that the IPCC uses (Fig. 8). Either individual experts or panels of experts can make qualitative estimates of uncertainty.

Term	Likelihood of the Outcome
Virtually certain	99-100% probability
Very likely	90-100% probability
Likely	66-100% probability
About as likely as not	33-66% probability
Unlikely	0-33% probability
Very unlikely	0-10% probability
Exceptionally unlikely	0-1% probability

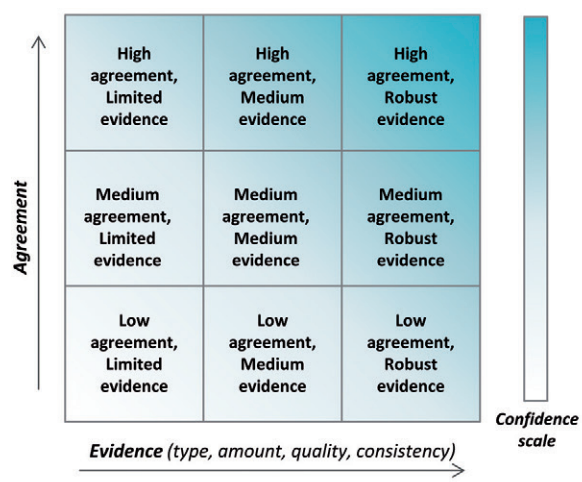


Figure 8.—Examples of a quantitative likelihood scale (left) and a qualitative confidence scale, as used by the Intergovernmental Panel on Climate Change. From Mastrandrea et al. (2010).

Box 8

DIY: Evaluate Uncertainty

There are a number of ways that uncertainty can be evaluated in a vulnerability assessment. Many vulnerability assessments may even use a combination of approaches. Below are examples of how uncertainty can be addressed.

Qualitative

- Using text to describe disagreements in the scientific literature or sources of error, or when there is insufficient information
- Evaluating multiple scenarios for a range of potential changes
- Assigning a qualitative ranking, such as the confidence determination used by the IPCC

Semiquantitative

- Giving each component of vulnerability a numerical uncertainty score that is summed or averaged for an overall score of confidence or uncertainty

Quantitative

- Using statistical tests or Monte Carlo simulations to arrive at a confidence interval or p-value
- Formal expert elicitation methods that arrive at a quantitative probability determination

Example: Evaluating Uncertainty

In our vulnerability assessments developed for the Climate Change Response Framework, a panel of experts qualitatively determined confidence for each vulnerability rating based on the framework developed for the IPCC (Fig. 9) (Mastrandrea et al. 2010). Confidence determinations took place at the in-person meetings during the discussion of each individual forest system in an assessment area. Panelists were asked to individually evaluate the amount of evidence that supported their vulnerability determination and the level of agreement among that evidence. In this fashion, evidence and agreement are two components of overall confidence in a vulnerability determination. Panelists evaluated confidence individually and as a group in a similar fashion to the vulnerability determination (Fig. 9).

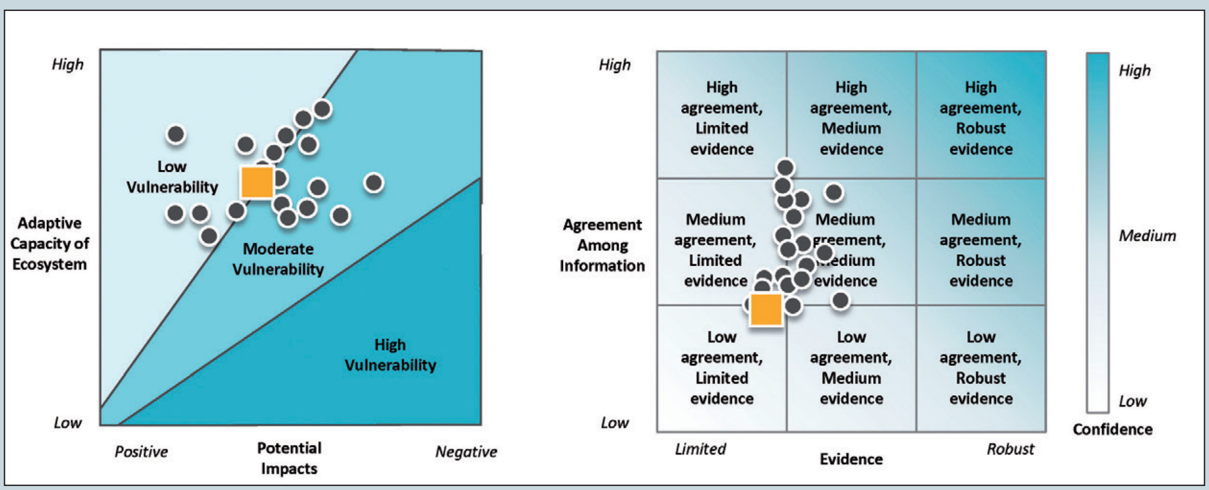


Figure 9.—Example confidence determination for a forest ecosystem during a vulnerability assessment conducted through the Climate Change Response Framework. Each expert panelist provides an individual determination of confidence in his or her vulnerability determination (circles). The group then comes to a consensus on confidence through discussion (square).

A Few Final Words

A good vulnerability assessment will be helpful in aiding management decisions. We have provided a few key factors to help you determine the quality and potential utility of existing assessments. However, managers and decisionmakers will ultimately determine whether the assessment is indeed useful for their planning or projects. If gaps remain, you can use the DIY boxes as a launching point to filling in those gaps.

We designed this as a brief guide to capture the key components of vulnerability assessments. If you are undertaking a new vulnerability assessment for a resource without much existing information, it may be helpful to reach out to experts for assistance.

Once you have a vulnerability assessment, what do you do with it? Chapters 3 and 4 offer strategies and approaches for climate adaptation in rural and urban forests. The Adaptation Workbook (Chapter 5) included in this set of Forest Adaptation Resources can walk you through the process of integrating climate change considerations into management plans and activities.

Checklist for Vulnerability Assessment Evaluation

The assessment's scale and scope:

- ☐ focuses on your resource of interest
- ☐ is at a geographic scale relevant to management of your resource

The assessment team has knowledge and expertise in:

- ☐ management of your resource of interest
- ☐ the social, biological, and physical science of your resource of interest
- ☐ the effects of climate change on your resource of interest
- ☐ the interaction of the above components

The peer-reviewed and gray literature are reviewed and cited to describe:

- ☐ past changes in climate in your geographic area
- ☐ projected changes in climate in your geographic area
- ☐ current conditions of your resource
- ☐ projected impacts of climate change on your resource

The assessment evaluates trends in:

- ☐ the climate of your assessment area
- ☐ your resource of interest

The assessment evaluates future projections of:

- ☐ the climate of your assessment area across a range of possible futures
- ☐ your resource of interest across a range of possible futures

The assessment qualitatively or quantitatively determines vulnerability of your resource. Most vulnerability assessments will include these three main components:

- ☐ exposure
- ☐ sensitivity
- ☐ adaptive capacity

The assessment qualitatively or quantitatively evaluates the uncertainty of:

- ☐ projected changes in climate
- ☐ projected impacts on your resource
- ☐ the vulnerability of your resource to climate change

CHAPTER 3. Adaptation Strategies and Approaches

One of the major challenges of adapting forest ecosystems to climate change is translating broad concepts into specific, tangible actions. This chapter addresses that challenge by providing a comprehensive synthesis of strategies and approaches, and a tiered structure that organizes this information. These strategies and approaches are designed to serve as stepping stones to enable natural resource managers to translate broad concepts into targeted and prescriptive actions for implementing adaptation (Box 9). Ten broad strategies and 36 more-specific approaches were synthesized from dozens of scientific papers that discussed adaptation actions at a variety of scales and locations. The strategies and approaches were reviewed by a diverse pool of natural resource professionals across the Midwest and Northeast, and are broadly applicable across a diversity of forests and other ecosystems. The strategies and approaches are presented as a menu of adaptation actions, which can then be adjusted and refined into tactics that help to achieve a specific management objective in a specific location. The Adaptation Workbook (Chapter 5) describes a structured process to help land managers use the menu and develop their own specific adaptation tactics. Example tactics are provided in this chapter primarily to illustrate a level of specificity; they are not comprehensive, but represent a few of the many possible tactics that could be used in forest ecosystems in the Midwest and Northeast.

Box 9

Using the Adaptation Strategies and Approaches

The adaptation strategies and approaches can provide:

- A full spectrum of possible adaptation actions that can help sustain healthy forest ecosystems and achieve management goals in the face of climate change
- A menu of adaptation actions from which managers select actions best suited to their specific management goals and objectives
- A platform for discussing climate change-related topics and adaptation methods
- Examples of tactics that could potentially be used to implement an approach, recognizing that specific tactics will be designed by the land manager.

The adaptation strategies and approaches do not:

- Make recommendations or set guidelines for management decisions. It is up to the land manager to decide how this information is used.
- Express preference for any strategies or approaches within an ecosystem type, location, or situation. Rather, a combination of location-specific factors and manager expertise is needed to inform the selection of any strategy or approach.

About the Adaptation Strategies and Approaches

Information on how to adapt natural ecosystems to the anticipated effects of climate change is rapidly growing as increasing numbers of land managers and researchers engage with the topic (Cross et al. 2012, Groves et al. 2012, Littell et al. 2012, Morelli et al. 2012, Schmitz et al. 2015, Staudinger et al. 2015, Stein et al. 2014). Until recently, adaptation literature was broad and generic, providing insufficient detail to enable natural resource managers to identify specific actions that facilitate adaptation while meeting management goals and objectives. At the same time, a flexible approach (rather than specific guidelines or recommendations) is needed to accommodate diverse management goals, geographic settings, local site conditions, and other management considerations. For these reasons, this set of adaptation strategies and approaches serves as a **menu** of potential adaptation actions. It helps natural resource managers identify their adaptation intention and supports them in developing and implementing their own specific adaptation actions. Managers can use this menu to choose the approaches that are most suitable to a particular management goal and ecosystem type. Although menu items can be applied in various combinations to achieve desired outcomes, not all items on the menu will work together. Furthermore, actions that work well in one ecosystem type may not work in another; it is up to the land manager to select appropriate actions for a specific project and specific goals.

Importantly, the adaptation strategies and approaches presented in this chapter are intended to build upon current management actions that work to sustain and conserve ecosystems over the long term. Many sustainable forest management and conservation activities already promote ecosystem health and resilience. Likewise, many adaptation actions are consistent with sustainable management (Innes et al. 2009, Ogden and Innes 2008) and efforts to restore ecosystem function and integrity (Harris et al. 2006, Millar and Brubaker 2006, Morelli et al. 2012, Stein et al. 2014). A changing climate may compel some managers to adopt new practices, but it can also underscore the importance of sustainable practices that are currently being used.

The adaptation strategies and approaches are part of a continuum of adaptation actions ranging from broad, conceptual application to practical implementation (Fig. 10). This continuum builds upon the adaptation framework described by Millar et al. (2007). The concepts of resistance, resilience, and transition serve as the fundamental options for managers to consider when responding to climate change:

- **Resistance** actions improve the defenses of an ecosystem against anticipated changes or directly defend the ecosystem against disturbance in order to maintain relatively unchanged conditions. Resistance may be appropriate when there is a desire or mandate to maintain a resource with high economic, cultural, or ecological value. Although this option may be effective in the short term (mid-century or sooner), it is likely that supporting persistence of the existing ecosystem will require greater resources and effort over the long term as the climate shifts further from historical norms. This option may also be most effective in ecosystems with low sensitivity to climate change (see Chapter 2), or in areas that are buffered from severe climate change impacts (e.g., refugia). As an ecosystem persists into an unfavorable climate, the risk of the ecosystem undergoing irreversible change (such as through a severe disturbance) increases over time.
- **Resilience** actions accommodate some degree of change, but encourage a return to near-prior conditions after a disturbance, either naturally or through management. Resilience can be fostered by the effects of periodic disturbance on a system, and the system's ability to persist after those disturbances, albeit with sometimes fluctuating populations (Holling 1973). Resilience actions enhance the ability of the system to bounce back from disturbance and tolerate changing environmental conditions,

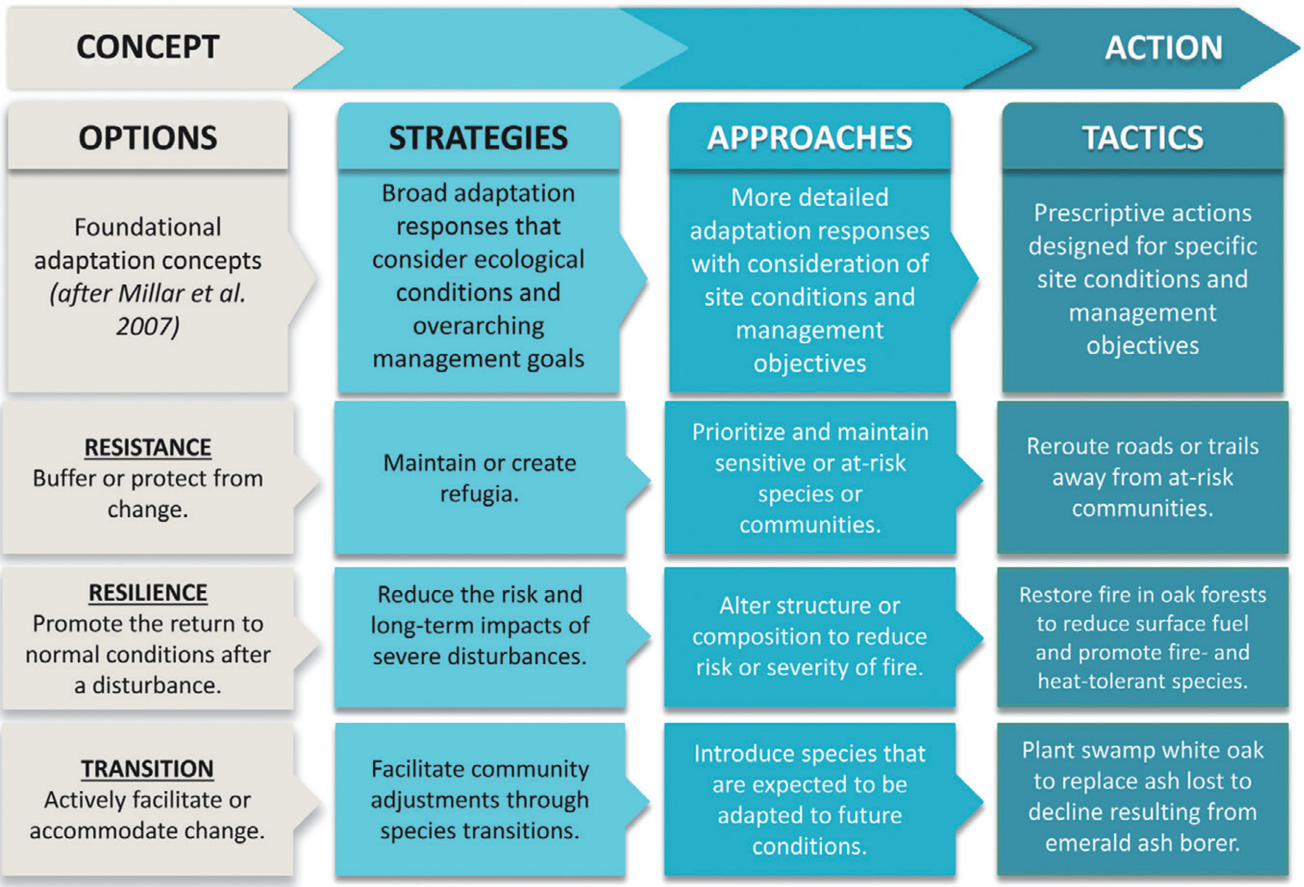


Figure 10.—A continuum of adaptation actions available to address needs at appropriate scales and levels of management (top four boxes) and examples of each level of action (in shaded boxes).

and may be most effective in systems that can already tolerate a wide range of environmental conditions and disturbance (i.e., high adaptive capacity; see Chapter 2). Like the resistance option, this option may be most effective in the short term and may be subject to increasing risk over time. Resilience is effective until the degree of change exceeds the ability of a system to cope, resulting in transition to another state.

- **Transition** actions (also referred to as "response" actions) intentionally anticipate and accommodate change to help ecosystems to adapt to changing and new conditions. Whereas resistance and resilience actions foster persistence of the current ecosystem, transition actions intentionally facilitate the transformation of the current ecosystem into a different ecosystem with clearly different characteristics. These actions may be considered appropriate in ecosystems assessed as highly vulnerable across a range of plausible future climates, such that the risk associated with resistance and resilience actions is judged to be too great (see Chapter 2). Transition actions are typically designed for long-term effectiveness. They are often phased into broader management plans that predominantly have a shorter-term focus on resilience actions.

These options of resistance, resilience, and transition serve as the broadest level in a continuum of adaptation responses to climate change (Janowiak et al. 2011). Along this continuum, actions for adaptation become increasingly specific. Adaptation strategies are abundant in recent literature and illustrate more-specific ways that adaptation options could be employed (Fig. 11). Strategies are,

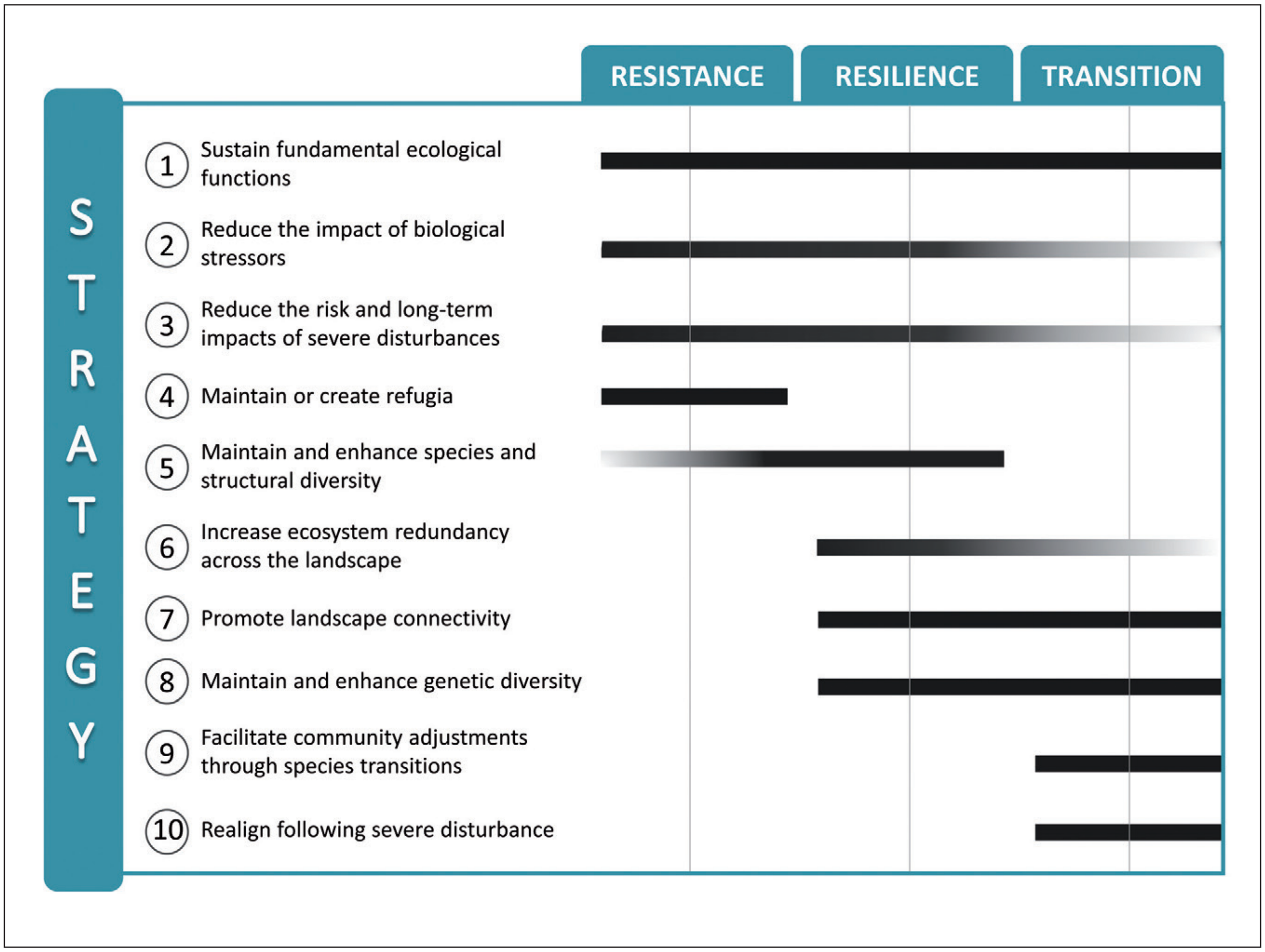


Figure 11.—Climate change adaptation strategies, which work to achieve three broad adaptation options: resistance, resilience, and transition. Strategies may be used under one or more options, and are generally arranged with strategies under resistance and resilience options first, and those under transition options last. A solid line indicates a strong relationship between an option and a strategy, whereas fading indicates that the strategy relates to that option under some circumstances. Although a strategy may work under multiple options, the implementation is likely to be achieved through very different approaches and tactics.

however, still very broad and can be applied in many ways across a number of landscapes and ecosystems. The 10 adaptation strategies are generally arranged to start with ideas that focus on the "resistance" adaptation option and then continue on to ideas that focus more on "transition," although this arrangement does not indicate preference or priority.

Adaptation approaches are even more specific, describing in greater detail how strategies could be employed. Differences in application among specific ecosystem types and management goals start to become evident. Ultimately, tactics are the most specific adaptation response on the continuum, providing prescriptive direction about what actions can be applied on the ground, and how, where, and when. Tactics can be developed only in relation to a species, the ecosystem type, site conditions, management objectives, and other factors. We have provided examples of tactics for each approach, but do not intend that they be implemented without due consideration of all relevant factors. The Adaptation Workbook (Chapter 5) is a structured process designed to be used in conjunction with vulnerability assessments and adaptation strategies and approaches to generate site-specific adaptation actions that meet explicit management and conservation objectives under a range of potential future climates. The Adaptation Workbook also provides a method to explicitly consider the benefits and drawbacks of potential adaptation tactics.

The remainder of this chapter provides a more detailed description of the 10 adaptation strategies and 36 more-specific approaches (Box 10). This menu was synthesized from a comprehensive literature review of adaptation actions at numerous scales and locations. Feedback from experts, including scientists, ecologists, and managers, was used to refine the adaptation strategies and approaches, as well as to provide examples of potential tactics in forests of the Midwest and Northeast (see Appendix 1 for methods).

Additionally, although these adaptation strategies and approaches were designed to assist land managers, many adaptation actions will require or benefit greatly from planning, education and outreach, research, or changes in policy or infrastructure (Box 11). The body of literature on adaptation is continually growing, so land managers and conservation professionals who are more focused on wildlife habitat, infrastructure, or fisheries may find similar lists of adaptation actions specific to their needs (Furniss et al. 2010, Staudinger et al. 2015, Stein et al. 2014). Common and scientific names of all species mentioned in this report are given in Appendix 2.

Forest on a fall day in the Upper Peninsula, Michigan. Photo by Kailey Marcinkowski, Michigan Technological University, used with permission.

Box 10

Menu of Adaptation Strategies and Approaches

Strategy 1: Sustain fundamental ecological functions.

1.1. Reduce impacts to soils and nutrient cycling.
1.2. Maintain or restore hydrology.
1.3. Maintain or restore riparian areas.
1.4. Reduce competition for moisture, nutrients, and light.
1.5. Restore or maintain fire in fire-adapted ecosystems.

Strategy 2: Reduce the impact of biological stressors.

2.1. Maintain or improve the ability of forests to resist pests and pathogens.
2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species.
2.3. Manage herbivory to promote regeneration of desired species.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances.

3.1. Alter forest structure or composition to reduce risk or severity of wildfire.
3.2. Establish fuelbreaks to slow the spread of catastrophic fire.
3.3. Alter forest structure to reduce severity or extent of wind and ice damage.
3.4. Promptly revegetate sites after disturbance.

Strategy 4: Maintain or create refugia.

4.1. Prioritize and maintain unique sites.
4.2. Prioritize and maintain sensitive or at-risk species or communities.
4.3. Establish artificial reserves for at-risk and displaced species.

Strategy 5: Maintain and enhance species and structural diversity.

5.1. Promote diverse age classes.
5.2. Maintain and restore diversity of native species.
5.3. Retain biological legacies.
5.4. Establish reserves to maintain ecosystem diversity.

Strategy 6: Increase ecosystem redundancy across the landscape.

6.1. Manage habitats over a range of sites and conditions.
6.2. Expand the boundaries of reserves to increase diversity.

Strategy 7: Promote landscape connectivity.

7.1. Reduce landscape fragmentation.
7.2. Maintain and create habitat corridors through reforestation or restoration.

Strategy 8: Maintain and enhance genetic diversity.

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range.
8.2. Favor existing genotypes that are better adapted to future conditions.

Strategy 9: Facilitate community adjustments through species transitions.

9.1. Favor or restore native species that are expected to be adapted to future conditions.
9.2. Establish or encourage new mixes of native species.
9.3. Guide changes in species composition at early stages of stand development.
9.4. Protect future-adapted seedlings and saplings.
9.5. Disfavor species that are distinctly maladapted.
9.6. Manage for species and genotypes with wide moisture and temperature tolerances.
9.7. Introduce species that are expected to be adapted to future conditions.
9.8. Move at-risk species to locations that are expected to provide habitat.

Strategy 10: Realign ecosystems after disturbance.

10.1. Promptly revegetate sites after disturbance.
10.2. Allow for areas of natural regeneration to test for future-adapted species.
10.3. Realign significantly disrupted ecosystems to meet expected future conditions.

Box 11

Adaptation Strategies for Planning and Policy

The Adaptation Strategies and Approaches for land managers have been designed for natural resource managers to use in planning on-the-ground management activities. However, many adaptation actions will require or benefit greatly from planning, education and outreach, research, or changes in policy or infrastructure. These higher-level actions may be vital for effective climate change adaptation across large scales, but they are beyond the scope of this document. Some examples of these actions are:

Planning

- Including risk management in forest plans and developing enhanced capacity for risk management (Johnston et al. 2006, Kellomaki et al. 2005, Ohlson et al. 2005)
- Documenting clear plans for how to respond to more frequent or severe disturbances in advance to allow for a faster, more thoughtful, better-coordinated response (Joyce et al. 2009)
- Using landscape-level planning and partnerships to identify and acquire high-priority areas for conservation or to share resources, expertise, and actions across jurisdictional boundaries (Anderson et al. 2012, D'Antonio et al. 2004, Mawdsley et al. 2009)
- Incorporating predicted climate change impacts into species and land management plans, programs, and activities (Mawdsley et al. 2009, Peterson et al. 2011, Swanston and Janowiak 2012)
- Increasing flexibility of planning goals and objectives to address dynamic processes, unexpected occurrences, and uncertainty (Millar et al 2008, Ogden and Innes 2007, Spies et al. 2010)
- Realigning management of significantly altered ecosystems to meet expected future environmental conditions (Groves et al. 2012, Millar et al. 2008, Morelli et al. 2012, Spittlehouse 2005)
- Linking adaptation planning to larger regional and national guidance documents that outline emerging principles for ecosystem-based adaptation (Manomet Center for Conservation Sciences and National Wildlife Federation 2013, Peterson et al. 2011).

Policy

- Reviewing and amending laws, regulations, or policies to improve their ability to support adaptation actions (Cross et al. 2012, Johnston et al. 2006, Mawdsley et al. 2009, Morelli et al. 2012, Peterson et al. 2011, Spittlehouse 2005)
- Managing populations of native herbivores (e.g., deer and moose), grazers (e.g., cattle), or invasive animals (e.g., feral hogs) by using landscape-level and cross-disciplinary planning
- Reevaluating seed zone sizes and rules governing the movement of seed stocks (Millar et al. 2007, Spittlehouse and Stewart 2003, Stein et al. 2013).

Infrastructure and Institutional Capacity

- Improving infrastructure and resources for species regeneration (e.g., nurseries) that focuses on providing a diversity of genetic material (Millar et al. 2007)
- Developing a gene management program to maintain diverse gene pools (Halofsky et al. 2011)
- Evaluating and diversifying the forest economy (e.g., timber sales and forest products) in response to changes in the market (Ogden and Innes 2008)
- Evaluating and improving road construction standards and stream crossings to minimize negative impacts on forest communities (Groves et al. 2012).

Research

- Bridging the gap between academic research and implementation by identifying current science and research needs (Swanston and Janowiak 2012)
- Creating climate change vulnerability assessments for a wide range of ecosystems and geographies (Swanston and Janowiak 2012)
- Developing decision-support tools that incorporate climate change information into management plans (National Fish Wildlife and Plants Climate Adaptation Partnership 2012, Stein et al. 2013, Swanston and Janowiak 2012).

Box 11 (continued)

Research (continued)

- Staging management activities as experiments to measure the effects or success of adaptation actions (Hemery 2008)
- Supporting and coordinating monitoring programs to track impacts of climate change and adaptation actions on ecosystems (Brandt et al. 2012, Cross et al. 2012, Morelli et al. 2012, National Fish Wildlife and Plants Climate Adaptation Partnership 2012, Swanston and Janowiak 2012)
- Including climate variables in growth-yield models (Kellomaki et al. 2005).

Education and Outreach

- Increasing the knowledge and experience of natural resource professionals, including decisionmakers and planners, so that they can better integrate climate change considerations into their projects and work plans (Groves et al. 2012, Morelli et al. 2012, National Fish Wildlife and Plants Climate Adaptation Partnership 2012, Stein et al. 2014, Swanston and Janowiak 2012)
- Creating training opportunities and communities of practice (National Fish Wildlife and Plants Climate Adaptation Partnership 2012, Swanston and Janowiak 2012)
- Preparing the public for adaptation principles through outreach (Groves et al. 2012, National Fish Wildlife and Plants Climate Adaptation Partnership 2012).

Adaptation Strategies and Approaches

Strategy 1: Sustain fundamental ecological functions

Climate change will have substantial effects on a suite of ecosystem functions, such as carbon storage, nutrient cycling, habitat, or water provisioning. As a result, many management actions will need to work both directly and indirectly to maintain the integrity of ecosystems in the face of climate change. This strategy seeks to sustain fundamental ecological functions, especially those related to soil and hydrologic conditions.

Approaches:

1.1. Reduce impacts to soils and nutrient cycling

Maintaining both soil quality and nutrient cycling are already common tenets of sustainable forest management (Burger et al. 2010, Oliver and Larson 1996) and can help improve the capacity of ecosystems to persist under new conditions. Physical and chemical changes can result from a variety of forest management and recreation activities, as well as from climate-related processes including fire, drought, and flooding. Examples of physical impacts to soil are compaction, mixing of soil layers, removal of organic layers, rutting, erosion, and landslides. Complex interactions among climate, vegetation, and landforms can result in changes in nutrient cycling, including the leaching or fixation of nutrients and changes in soil biota. Many existing guidelines and best management practices describe actions that can be used to reduce impacts to soil and water; many of these actions are also likely to be beneficial in the context of adaptation, either in their current form or with modifications to address potential climate change impacts.

Examples of adaptation tactics are:

- Altering the timing of forest operations to reduce potential impacts on water, soils, and residual trees, especially in areas that rely on particular conditions for operations that may be affected by a changing climate (e.g., frozen soil, or dry conditions)
- Modifying forest operations techniques and equipment (e.g., using pallets, debris mats, or float bridges) to minimize soil compaction, rutting, or other impacts on water, soils, and residual trees
- Retaining coarse woody debris to maintain moisture, soil quality, and nutrient cycling
- Restricting recreational access in areas that show signs of excessive wear on natural resources in order to allow for revegetation or soil stabilization
- Using soil amendments to restore or improve soil quality (e.g., using lime to increase base cations in the soil profile in areas affected by long-term acid deposition)
- Restoring native herbaceous groundcover following management activities in order to retain soil moisture and reduce erosion.

1.2. Maintain or restore hydrology

Projected changes in precipitation and temperature are expected to alter hydrologic regimes through changes in streamflow, snowpack, evapotranspiration rates, soil moisture, surface runoff, infiltration, flooding, and drought (Jones 2011). Hydrologic changes could occur gradually or rapidly through extreme events. Some ecosystems are very susceptible to stress from drought, which may increase in frequency, severity, duration, or extent as a result of changing precipitation patterns. Other ecosystems are susceptible to flooding and ponding. Maintaining sufficient water levels and flow patterns is critical to ecosystem function. Hydrology can be altered by infrastructure (e.g., dams, roads, and other impervious surfaces), excessive groundwater extraction, stream channelization, and even invasive plants (Massachusetts Division of Fisheries and Wildlife 2006). Existing infrastructure that diverts water, or otherwise alters hydrology, may need to be reevaluated to compensate for changes in water levels or flows (Brandt et al. 2012, Furniss et al. 2010, Galatowitsch et al. 2009). Infrastructure will also need to be designed to accommodate greater hydrologic extremes in the future. It is important to keep in mind that modifications to maintain hydrology at one site may have negative impacts on hydrology at another site.

Examples of adaptation tactics are:

- Upgrading culvert size and cleaning culverts regularly to accommodate changes in peak flow and thus reduce damage to infrastructure and the environment during heavy rain events. This example may also incorporate ecologically based stream crossing designs that allow passage for aquatic organisms.
- Reducing or eliminating agricultural drainage improvements near wetlands
- Reducing groundwater withdrawals in recharge areas of calcareous fens
- Installing berms or dikes to divert surface water to a lowland area affected by decreased precipitation
- Removing or modifying dams, especially as they become defunct, and if they have little hydroelectric or irrigation value
- Decommissioning or temporarily closing roads to reduce erosion and sedimentation and to restore permeability and soil hydrology.

1.3. Maintain or restore riparian areas

Forests located within riparian areas serve important ecosystem functions, such as decreasing soil erosion, filtering water, and storing and recycling organic matter and nutrients (Barling and Moore 1994, Brandt et al. 2012, Castelle et al. 1994). Trees in riparian areas also provide shade, which helps to buffer stream temperatures. Forested riparian areas can serve as corridors for wildlife and plant species migrating across otherwise fragmented landscapes (Heller and Zavaleta 2009). Many of these functions and benefits may be degraded if riparian forests undergo decline or exacerbated stress from climatic shifts and extreme events. The use of protective guidelines, such as best management practices and riparian management zones, can be used to avoid damage or additional stress to riparian areas during management activities.

Examples of adaptation tactics are:

- Restoring or promoting a diversity of tree and plant species to increase stream shading, provide a source of woody debris, stabilize the soil, and provide habitat and connectivity for wildlife
- Anchoring with fabric, wire, or natural materials in order to stabilize eroding stream banks
- Creating buffers along riparian areas with reduced or no harvest based on the landform, hydrology, and vegetation of the riparian zone in addition to any recommended buffer distance
- Restoring or reforesting riparian areas adjacent to agricultural areas in order to reduce erosion and nutrient loading into adjacent water bodies
- Managing water levels to supply proper soil moisture to vegetation adjacent to the stream during critical time periods, either by manipulation of existing dams and water control structures or restoration of natural dynamic water fluctuations
- Reconnecting floodplains to rivers and restoring natural floodplain conditions and associated native habitats (e.g., bottomland forest, wetlands, and wet prairie and other grasslands) in order to restore fluvial processes.

1.4. Reduce competition for moisture, nutrients, and light

Competition for resources between plants is established as one of the main mechanisms in plant succession and evolution (Weiner 1990). Competition occurs aboveground as plants compete for light, and belowground as they compete for water and mineral nutrients (Casper and Jackson 1997). Climate change is expected to affect many of the competitive relationships in forest ecosystems. Productivity may increase because of the positive effects of carbon dioxide (CO_2) fertilization and longer growing seasons. But not all species will be able to take equal advantage of these positive effects (Evans and Perschel 2009). Reducing competition for resources can enhance the persistence of desired species and increase the ability of ecosystems to cope with the direct effects (drought stress, temperature increases) and indirect effects (increased damage from pests and disease) of climate change (Dwyer et al. 2010, Evans and Perschel 2009).

Examples of adaptation tactics are:

- Using herbicide or mechanical thinning to prevent the encroachment of woody competitors and invasive species, especially after disturbance
- Thinning forest stands to remove crowded, damaged, or stressed trees in order to reduce competition for light, nutrients, and water
- Using prescribed fire to maintain growing space for fire-tolerant species or to increase nutrient turnover
- Fertilizing or amending soil to address nutrient deficiencies. Although the benefit is faster growth, there could be consequences from nutrient leaching, such as stream eutrophication.
- Controlling beech suckers, sprouts, and brush with herbicides or mechanical treatment in areas affected by beech bark disease in order to reduce competition with the regeneration of other species.

1.5. Restore or maintain fire in fire-adapted ecosystems

Long-term fire suppression leads to shifts in ecosystem structure and composition, which may disproportionately favor certain species and reduce biodiversity (Nowacki and Abrams 2008). Restoring fire regimes that attempt to mimic natural disturbance in fire-adapted systems can enhance regeneration and encourage stronger competition by fire-dependent and fire-tolerant species (Abrams 1992). These actions can simultaneously foster more complex ecosystem structure and reduce the risk of severe wildfire. Projecting the effects of climate change on fire regimes in forest ecosystems is an area of active research. The wildfire season is expected to lengthen in much of the Midwest and Northeast, and wildfires may occur more frequently (Flannigan et al. 2009a, 2009b; Guyette et al. 2014; Moritz et al. 2012; Tang et al. 2014). Helping fire-adapted ecosystems tolerate these potential changes may be the focus of adaptation actions.

Examples of adaptation tactics are:

- Using prescribed fire to reduce ladder fuels, invasive species, and understory competition
- Promoting fire- and drought-adapted species and ecosystems in areas that are expected to have increased fire risk as a result of climate change
- Using natural or prescribed fire to restore the open character of oak woodlands and glades
- Shifting prescribed burn seasons to align with projected seasonal precipitation changes, thereby reducing the risk of unintended wildfire conditions.

Strategy 2: Reduce the impact of biological stressors

Biological stressors such as insects, pathogens, invasive species, and herbivores can act individually and in concert to amplify the effects of climate change on ecosystems. Forest managers already work to maintain the ability of forests to resist stressors. As an adaptation strategy, these efforts receive added effort and focus, with an emphasis on anticipating and preventing increased stress before it occurs. Climate change has the potential to add to or intensify the impact of many biological stressors, such as forest pests and invasive plant species, which heightens the importance of responding to these issues. Dealing with these existing stressors is a relatively high-benefit, low-risk strategy for climate change adaptation, in part because of the existing body of knowledge about their impacts and solutions (Climate Change Wildlife Action Plan Work Group 2009).

Approaches:

2.1. Maintain or improve the ability of forests to resist pests and pathogens

Even modest changes in climate may cause substantial increases in the distribution and abundance of many insect pests and pathogens, potentially leading to reduced forest productivity or increased tree stress and mortality (Ayres and Lombardero 2000, Dukes et al. 2009). Impacts may be exacerbated where site conditions, climate, other stressors, and interactions among these factors increase the vulnerability of forests to these agents (Spittlehouse and Stewart 2003). Actions to manipulate the density, structure, or species composition of a forest may reduce susceptibility to some pests and pathogens (Spies et al. 2010).

Examples of adaptation tactics are:

- Thinning to reduce the density of a pest's host species in order to discourage infestation, based on the knowledge that species are especially susceptible to pests and pathogens at particular stocking levels
- Adjusting rotation length to decrease the period of time that a stand is vulnerable to insect pests and pathogens, based on the knowledge that species are especially susceptible to pests and pathogens at particular ages
- Creating a diverse mix of forest or community types, age classes, and stand structures to reduce the availability of host species for pests and pathogens
- Using pesticides or biological control methods to manage pest populations (e.g., gypsy moth, Asian longhorned beetle, or hemlock woolly adelgid) in heavily infested areas
- Restricting harvest and transportation of logs near stands already heavily infested with known pests or pathogens
- Using impact models and monitoring data to anticipate the arrival of pests and pathogens and prioritize management actions.

2.2. Prevent the introduction and establishment of invasive plants and remove existing invasive species

Hundreds of nonnative invasive plant species are currently present in the Midwest and Northeast (Chornesky et al. 2005, Natural Resources Conservation Service 2012). Climate change is expected to increase habitat for many of these species, which may be poised to outcompete native species (Chornesky et al. 2005, Millar et al. 2007). Current methods for controlling nonnative invasive species emphasize early detection and rapid response to new infestations (Hellmann et al. 2008). Management of highly mobile nonnative invasive species may require increased coordination across property boundaries and over larger geographic areas, and is likely to require an increasing budget for eradication efforts. As a resistance or resilience strategy, this approach may work for a while. Over the long term, limitations in available resources may require managers to prioritize which species to eradicate and which species to allow to occupy a site.

Examples of adaptation tactics are:

- Increasing monitoring for known or potential invasive species to ensure early detection, especially at trailheads, along roads, and along other pathways known for infestation
- Eradicating existing populations or seed sources (e.g., upstream) of invasive plants through physical or chemical treatments
- Cleaning equipment prior to forest operations in order to prevent the spread of invasive plants during site preparation, harvesting, or other activities
- Maintaining closed-canopy conditions to reduce the ability of light-loving invasive species to enter the understory
- Educating staff and volunteers on identification and eradication of current and potential invasive species.

2.3. Manage herbivory to promote regeneration of desired species

Climate change has the potential to exacerbate many forest stressors and alter regeneration patterns. Additionally, climate change will probably have direct and indirect effects on populations of forest herbivores such as moose (generally expected to decrease) and white-tailed deer (generally expected to increase). Because herbivores preferentially browse on particular species, it may be increasingly important to protect regeneration of desired species from deer, moose, and other herbivores. Much of the available information on forest herbivores focuses on white-tailed deer and moose, which are considered keystone species capable of dramatically altering forests across the Midwest and Northeast (Frerker et al. 2014, Horsley et al. 2003, Mladenoff and Stearns 1993, Rooney and Waller 2003, Stromayer and Warren 1997). Managing herbivory alone may not promote desired species. Thus, this approach may be combined with other approaches that release advance regeneration or stimulate new regeneration.

Examples of adaptation tactics are:

- Applying repellant or installing fences, bud caps, and other physical barriers to prevent herbivory
- Promoting abundant regeneration of multiple species in order to supply more browse than herbivores are expected to consume
- Using tree tops from forest harvest or plantings of nonpalatable tree species as locations for “hiding” desirable species from herbivores to reduce browse pressure
- Partnering with state wildlife agencies to monitor herbivore populations or reduce populations to appropriate levels.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances

Climate change is projected to increase the potential for severe disturbance events, such as wildfire, extreme wind, and ice storms (Intergovernmental Panel on Climate Change [IPCC] 2012, Moritz et al. 2012, Uriarte and Papaik 2007). These disturbances have the ability to alter community composition and structure over large landscapes. Disturbances can interact with other stressors (Papaik and Canham 2006). For example, extreme wind events can cause tree damage and mortality, which increase the risk of pest outbreaks or wildfire (Gandhi et al. 2007, Woodall and Nagel 2007). Even as trends continue to emerge, management will need to adjust appropriately to the changes in natural disturbance dynamics (Heller and Zavaleta 2009).

Approaches:

3.1. Alter forest structure or composition to reduce risk or severity of wildfire

Forest structure and composition may interact with longer and drier growing seasons to increase the risk of wildfire. Mortality from climate-related disturbances can lead to increases in fuel loading, which can increase the risk or severity of fire. Although some forest types are tolerant of or dependent on fire, extremely hot fires can destroy seed banks, sterilize soils, induce hydrophobic soil conditions, or cause tree mortality (Nitschke and Innes 2008, Noss 2001). Management actions to alter species composition or ecosystem structure may reduce susceptibility to these threats (Hulme 2005, Spittlehouse and Stewart 2003).

Examples of adaptation tactics are:

- Using prescribed fire and thinning to reduce surface fuels, increase height to live crown, decrease crown closure, and create a more open forest structure that is expected to be less vulnerable to severe wildfire
- Using prescribed fire to maintain open conditions in ecosystems at lower elevations as a means of reducing fuels and the risk of wildfire in ecosystems at higher elevations
- Promoting fire-resistant species, such as hardwoods, in buffer zones between more-flammable conifers to slow the movement of wildfires
- Physically removing dead or dying trees or other vegetation to reduce surface and ladder fuels, while minimizing exposure to invasive plants, pests, or pathogens.

3.2. Establish fuelbreaks to slow the spread of catastrophic fire

Projected increases in fire occurrence as a result of climate change are expected to increase demand on fire-fighting resources and may force prioritization of fire suppression efforts to targeted areas (Millar et al. 2007, Spittlehouse and Stewart 2003). Managers may seek to reduce the spread or intensity of fire by using a fuelbreak, which is a physical barrier such as a road, bulldozer line, or water body. Establishing fuelbreaks can be complementary with actions to reduce the fuel load of the forest itself (Agee et al. 2000). Fuelbreaks can be created to lessen fire spread and intensity in specific areas, such as the wildland-urban interface, but also have the potential to increase fragmentation.

Examples of adaptation tactics are:

- Using prescribed fire or mechanical thinning to lower the volume of dense vegetation and reduce flammability within a buffer zone of appropriate size for the landscape
- Creating fire lines (i.e., areas where all vegetation is removed down to mineral soil) between a flammable stand and the wildland-urban interface or a fire-intolerant stand
- Establishing fuelbreaks along roads, power lines, and other existing features in order to reduce the spread of wildfire while minimizing additional fragmentation
- Replacing vegetation with nonflammable materials (e.g., replacing vegetation with local rocks) around high-priority areas
- Removing edge vegetation and lower branches of perimeter trees of flammable stands (e.g., pine islands) to arrest the path of fire from the ground surface to the tree crown.

3.3. Alter forest structure to reduce severity or extent of wind and ice damage

Wind disturbance is a fundamental process in many forest ecosystems across the Midwest and Northeast (Frelich 2002, Seymour et al. 2002). Wind events and the ensuing effects on forests are expected to become more frequent and severe under climate change (Fischlin et al. 2009, Frelich and Reich 2010), although there are many challenges in predicting the size, frequency, and intensity of these events. Some stands may have structures poorly suited to withstand projected increases in storm intensity. Silvicultural techniques exist to alter forest composition and structure for increased resistance to blowdown or ice damage, or to avoid sudden exposure of retained trees to wind (Burton et al. 2008, Everham and Brokaw 1996, Mitchell 2013).

Examples of adaptation tactics are:

- Retaining trees at the edge of a clearcut or surrounding desirable residual trees to help protect trees that have not been previously exposed to wind
- Conducting forest harvest over multiple entries in order to gradually increase the resistance of residual trees to wind
- Using directional felling, cut-to-length logging, and other harvest techniques that minimize damage to residual trees
- Creating canopy gaps that have an orientation and shape informed by the prevailing winds in order to reduce the risk of windthrow.

3.4. Promptly revegetate sites after disturbance

Potential increases in the frequency, intensity, and extent of large and severe disturbances may disrupt regeneration and result in loss of forest cover, productivity, or function in the long term. Prompt revegetation of sites following disturbance helps reduce soil loss and erosion, maintain water quality, and discourage invasive species in the newly exposed areas. These efforts can also provide an opportunity to promote natural regeneration or foster species that may be better adapted to future conditions.

Examples of adaptation tactics are:

- Planting species expected to be adapted to future conditions and resistant to insect pests or present pathogens
- Creating suitable physical conditions for natural regeneration through site preparation, for example by chaining after a burn to promote seed establishment
- Monitoring areas of natural regeneration on a more frequent basis, and prioritizing planting or seeding where natural regeneration is slow to succeed
- Planting larger individuals (saplings versus seedlings, or containerized versus bare-root stock) to help increase survival in sites where dry conditions are expected.

Tamarack cones in the fall in the Upper Peninsula, Michigan. Photo by Kailey Marcinkowski, Michigan Technological University, used with permission.

Strategy 4: Maintain or create refugia

Refugia are areas that have resisted ecological changes occurring elsewhere, often providing suitable habitat for relict populations of species that were previously more widespread (Keppel et al. 2012, Millar et al. 2007). Climate refugia are often formed by topography (e.g., north sides of slopes, or sheltered ravines), proximity to large water bodies, or connection to groundwater (Ashcroft 2010, Dobrowski 2011). During previous periods of rapid climate change, at-risk populations persisted in refugia that avoided extreme impacts (Keppel et al. 2012, Millar et al. 2007, Noss 2001). These populations allowed species to persist until more favorable climatic conditions returned and species were able to expand into newly available habitats. This strategy seeks to identify and maintain ecosystems that: (1) are on sites that may be better buffered against climate change and short-term disturbances, and (2) contain communities and species that are at risk across the greater landscape (Millar et al. 2007, Noss 2001).

Approaches:

4.1. Prioritize and maintain unique sites

Some sites host a higher diversity of species than adjacent sites, have many endemic species, have a sheltered topographic position, or have retained species through past periods of climate change (Keppel et al. 2012). These potential refugia are formed through spatial, geophysical, and biological variation on the landscape and may be identified as unique sites that are expected to be more resistant to change. These sites may provide the best chance to retain habitat for native species under future climate change (Anderson et al. 2012). Species at these sites are not necessarily sensitive or at-risk, although they may face increased stress under future climate on some landscape positions. Committing additional resources may be necessary to ensure that the characteristic site conditions are not degraded by invasive species, herbivory, fire, or other disturbances.

Examples of adaptation tactics are:

- Identifying and managing cooler and wetter locations that are expected to be more resistant to changes in climate as refugia for maintaining native plant communities into the future
- Limiting harvest or management-related disturbance in areas that may be buffered from climate change (e.g., spring-fed stands sheltered in swales or valleys)
- Identifying and protecting a network of sheltered mountain slopes, valleys, or forests with continuous shading canopy
- Identifying areas with a high diversity of geology, landform, vegetation, or soils for increased protection or conservation
- Protecting areas that have been generally undisturbed by humans, such as those within old-growth forest, peatlands, barrens, or prairie, in order to preserve a reference condition or legacy.

4.2. Prioritize and maintain sensitive or at-risk species or communities

Many species are projected to decline as a result of climate change. For example, northern and boreal species are widespread in northern portions of the Midwest and Northeast, but are likely to lose habitat because they are already at the southern extent of their range (Swanston et al. 2011). Other species may be more vulnerable due to their dependence on a narrow range of site conditions. Identifying and maintaining sensitive or at-risk species as long as possible may help them persist until new long-term sites can be located and populated.

Examples of adaptation tactics are:

- Using impact models and monitoring data to identify and prioritize management of species expected to decline under future conditions
- Retaining individuals of a priority species across many diverse sites representing various environmental conditions or within differing forest types

- Rerouting roads or trails away from at-risk communities to reduce damage from traffic or reduce the risk of introducing invasive species
- Minimizing harvest and other disturbances to species with dispersal or migration barriers, such as high-elevation or lowland conifer species, in order to protect viable populations where they currently occur
- Monitoring regeneration to detect migration of plant populations or communities to adjacent areas.

4.3. Establish artificial reserves for at-risk and displaced species

Species already exist outside their natural habitats in nurseries, arboretums, greenhouses, botanical gardens, and urban environments around the world. These highly controlled environments may be used to support individuals or genetic lineages that are no longer able to survive in their former location, or to serve as interim refugia for rare and endangered plant species that have specialized environmental requirements and low genetic diversity (Fiedler and Laven 1996, Havens et al. 2006, Millar 1991, Vitt et al. 2010). These artificial reserves may in some cases maintain species until they can be moved to new suitable habitat. Although a controlled environment would probably require substantial resources, this approach may be critical for at-risk species (Coates and Dixon 2007).

Examples of adaptation tactics are:

- Using an existing artificial reserve to cultivate species after suitable habitat has shifted and when they face considerable lag time before new habitat may become available
- Collecting seeds and other genetic material of at-risk species to contribute to a genetic repository
- Planting individuals in a protected location expected to provide suitable habitat in a natural setting, such as a stand on a partner's property
- Planting individuals in a controlled setting, such as a climate-controlled arboretum or botanical garden.

Strategy 5: Maintain and enhance species and structural diversity

Land managers already work to increase structural and species diversity in many cases, and as an adaptation strategy this general goal receives added effort and focus (Mooney et al. 2009). Structural and species diversity may buffer a community against the susceptibility of its individual components to climate change (Peterson et al. 1998). In other words, a community may still experience stress as individual components fare poorly, but the redundancy of particular roles and variability among all species' responses contribute to the resilience of the community (Elmqvist et al. 2003). Although a forest is often defined by its dominant or most abundant species, even rare species can act as keystone species or contribute to the suppression of invasive exotic plants (Mooney et al. 2009).

Approaches:

5.1. Promote diverse age classes

Species are vulnerable to stressors at different stages in their life cycle. Even-aged stands are often more vulnerable to insect pests and diseases, many of which are likely to increase in range and severity as a result of climate change. In uneven-aged systems, a smaller proportion of the population may be exposed to a particular threat at any one time, which can increase the resistance or resilience of a stand to a wider range of disturbances (O'Hara and Ramage 2013). Maintaining a mix of ages, sizes, or canopy positions will help buffer vulnerability to stressors of any single age class, as well as increase structural diversity within stands or across a landscape (Noss 2001).

Examples of adaptation tactics are:

- Emulating aspects of disturbances through forest management techniques such as variable-density treatments or irregular return intervals in order to encourage the development of multiple age cohorts
- Focusing salvage operations on creating desired residual stand structures following disturbance, even if less merchantable timber is removed as a result

- Using site scarification, planting, or other techniques to support adequate regeneration
- Maintaining a variety of age classes of a given forest type across a larger landscape.

5.2. Maintain and restore diversity of native species

Diverse communities may be less vulnerable to climate change impacts and disturbances because they distribute risk among multiple species, reducing the likelihood that the entire system will decline even if one or more species suffer adverse effects. This may be especially important in communities with low diversity; even small increases in diversity may increase resilience without greatly altering species composition (Anderson and Chmura 2009, Cadotte et al. 2012, Wilkerson and Sartoris 2013). Forests with higher levels of species diversity are also expected to be less vulnerable to declines in productivity due to climate change (Duveneck et al. 2014).

Examples of adaptation tactics are:

- Using silvicultural treatments to promote and enhance diverse regeneration of native species
- Transitioning plantations to more complex systems by underplanting or promoting regeneration of a variety of native species expected to do well under future conditions
- Planting desired native species within an area that is otherwise expected to regenerate naturally in order to add diversity
- Restoring native vegetation on areas that have been severely altered by anthropogenic activities, such as abandoned agricultural areas or surface mines
- Planting species with diverse timing of phenological events (e.g., flowering, fruiting, leaf out, leaf drop) to provide necessary resources over a longer time frame to forest-dependent wildlife species.

5.3. Retain biological legacies

Biological legacies are organisms, structures, or patterns inherited from a previous ecosystem and often include mature trees, snags, and down logs remaining after natural disturbance or harvesting (Society of American Foresters 2008). Biological legacies can enhance species and structural diversity, serve as a seed source, or provide nurse logs for seed germination (Gunn et al. 2009). Mature trees can often survive through periods of unfavorable climate, even while conditions become unsuitable for seedling establishment (Brubaker 1986). In a changing climate, biological legacies may play a critical role in a species' persistence or colonization of new habitat (Gunn et al. 2009).

Examples of adaptation tactics are:

- Retaining the oldest and largest trees with good vigor during forest management activities
- Retaining survivors of pest or disease outbreaks, droughts, windthrow events, or other disturbances during salvage or sanitation operations
- Retaining individual trees of a variety of uncommon species to maintain their presence on the landscape.

5.4. Establish reserves to maintain ecosystem diversity

Some areas with exemplary combinations of soil, hydrologic, and climatic variation support a correspondingly high degree of species diversity. Ecosystems in the areas may be protected through the establishment of reserves. Reserves are traditionally defined as natural areas with little to no harvest activity that do not exclude management of fire or other natural disturbance processes (Halpin 1997). However, the use and definition of reserves may need to be evaluated within the context of changing climate and forest response. It may be valuable to retain explicit flexibility in management practices, so long as management directly supports the justifications and goals for establishing the reserve. This approach may also be used as a "control" for monitoring adaptation actions implemented in other forest stands.

Examples of adaptation tactics are:

- Identifying areas with high diversity or other desirable attributes that can be set aside as a reserve on an existing ownership
- Setting a minimum requirement for percentage of land in reserve
- Prioritizing areas where riparian corridors connect core areas to other reserves and habitats
- Providing a large reserve based on a species' known optimum conditions in order to preserve a species.

Northern white-cedar trunk in the Upper Peninsula, Michigan. Photo by Kailey Marcinkowski, Michigan Technological University, used with permission.

Strategy 6: Increase ecosystem redundancy across the landscape

Some losses are inevitable, whether due to catastrophic events or unforeseen interactions of management, climate change, and forest response. Increasing ecosystem redundancy attempts to lower the overall risk of losing a species or community by increasing the extent, number of occurrences across the landscape, and diversity of regeneration stages (Akçakaya et al. 2007). This strategy may benefit greatly from developing partnerships with other land management organizations and coordinating landscape-scale conservation practices.

Approaches:

6.1. Manage habitats over a range of sites and conditions

The suitable site conditions for a community or species may shift on the landscape as climate changes, resulting in new combinations of locations and species aggregations. This may increase opportunities for successful regeneration and the likelihood of persistence of a species or community (Joyce et al. 2009, Millar et al. 2007, The Nature Conservancy 2009). Species currently covering a large extent may provide many options for retaining redundancy across the landscape.

Examples of adaptation tactics are:

- Restoring or increasing a community type on a variety of soil types and across a range of topographic positions
- Implementing a variety of forest management activities or silvicultural prescriptions across multiple stands or areas with similar starting conditions in order to diversify forest conditions and evaluate different management approaches
- Coordinating with partners to manage an at-risk species or community existing on a variety of suitable sites.

6.2. Expand the boundaries of reserves to increase diversity

Approaches 4.1 and 5.4 describe protecting and maintaining climate refugia and reserves to maintain ecosystem diversity and legacy. Expanding existing reserve boundaries may buffer and replicate the diversity within the core of the reserve, but more importantly, may also increase the overall species diversity within the expanded reserve (Akçakaya et al. 2007). This approach may be more effective over the long term if focused on reserves that also encompass climate refugia.

Examples of adaptation tactics are:

- Restoring or conserving land directly adjacent to established reserves
- Developing a network of reserves with adjacent landowners with shared conservation goals
- Designating buffer zones of low-intensity management around core reserve areas and between different land uses.

Strategy 7: Promote landscape connectivity

Species migration is a critical factor in the maintenance of ecosystem function in a changing climate, but fragmentation of landscapes and loss of habitat may restrict species movement and gene flow (Davis and Shaw 2001, Iverson et al. 2004a). Managing the landscape for connectivity may allow for easier species movement, reduce lags in migration, and enhance the flow of genetic material. The current rate of climate change coupled with contemporary land use, however, creates unique challenges to migration. Many species are not expected to be able to migrate at a rate sufficient to keep up with climate change and associated range shifts (Davis and Shaw 2001, Iverson et al. 2004a). Therefore, it may be beneficial to combine the approaches under this strategy with efforts to create refugia or relocate species (i.e., assisted migration). But connectivity may also increase movement of invasive species and insect pests, thereby increasing the need to prevent introduction of these species.

Approaches:

7.1. Reduce landscape fragmentation

The fragmentation of contiguous forest habitats is a primary driver of biodiversity loss and reduced productivity through exposure to disturbance, obstruction of migration pathways, and overall lowered resilience (Fischer and Lindenmayer 2007). Protecting large areas from fragmentation will require a concerted effort to create partnerships, agreements, and other mechanisms for land protection and management across property boundaries. Strategic acquisition of high-priority conservation areas, conservation easements, certification programs, restoration projects, and other efforts to increase the size and connectivity of forest ecosystems will foster a landscape-level response to counter the widespread effects of climate change (Anderson et al. 2012, Millar et al. 2007, Spittlehouse and Stewart 2003). This approach may be facilitated by approach 5.4, which focuses on establishing new reserves.

Examples of adaptation tactics are:

- Using geospatial information to identify new and existing migration corridors
- Restoring native vegetation and vegetation structure in degraded areas within the forested matrix
- Establishing partnerships and coordinating acquisition of conserved forest lands or riparian areas to achieve common management goals
- Establishing or expanding reserves adjacent to other forest blocks to form a connective network of a few large reserves, many small reserves along a climatic gradient, or a combination of large and small reserves close to each other
- Promoting or participating in conservation easement programs that retain forest cover and achieve landscape-scale connectivity.

7.2. Maintain and create habitat corridors through reforestation or restoration

The presence of both small and large corridors on the landscape may help species to migrate without additional assistance (Heller and Zavaleta 2009). Corridors oriented in any direction may be useful to facilitate genetic mixing, but corridors arranged along climatic or elevational gradients may be more useful if the goal is to allow for species movements along the gradient. Reforestation or restoration of riparian areas may help retain species on the landscape longer while providing a forested corridor.

Examples of adaptation tactics are:

- Establishing or restoring forest cover along rivers or ridges to build on natural linear features that connect larger forests
- Setting aside a connected network of conservation easements
- Eradicating invasive species within a corridor in order to minimize competition with desired species
- Working with partners on the landscape to identify high-priority sites to protect for landscape-scale corridors or habitat.

Strategy 8: Maintain and enhance genetic diversity

Greater genetic diversity may help species adjust to new conditions or sites by increasing the likelihood that some individuals within a species will be able to withstand climate-induced stressors. Current guidelines for management of tree genes generally promote the conservation of local gene pools, restrict transfer of germplasm, and define small seed zones to minimize contamination between pools (Millar et al. 2007). A changing climate may require new guidelines that accommodate shifting seed zones and promote more options for increasing genetic diversity. Actions to enhance genetic diversity could be timed to occur after large-scale disturbances to take advantage of regeneration and establishment phases. Approaches under this strategy are best implemented with great caution, considering the uncertainties inherent in climate change, the sparse record of previous examples, the ecological and social suitability of particular locations, and continued uncertainties of forest response.

Approaches:

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range

Planted seedlings typically have greater survival when they originate from local seed sources, but local seed sources may no longer produce the best adapted seedlings if the governing environmental factors change (Vitt et al. 2010). Using seed zones that change over time and are based on regional analyses of climate change data may provide better seed sources than static seed zones (Erickson and Navarrete-Tindall 2004, Millar et al. 2007, Spittlehouse and Stewart 2003). This may entail importing genetic stock from locations ranging from nearby to substantially distant in order to introduce plants that are expected to be better adapted to current or future climatological conditions. At the same time, ecoregional and political boundaries may continue to restrict the distance from which new species or genotypes may be imported (McKenney et al. 2009, Pedlar et al. 2012). This strategy may require communicating with policy-makers to reevaluate seed zone sizes and rules governing the movement of seed stocks. It is important to note that although many environmental factors may match seedlings to geographic areas, limitations such as cold tolerance may remain (Millar et al. 2007). It is also important to take the necessary precautions to avoid introducing a new invasive species (Vitt et al. 2010).

Examples of adaptation tactics are:

- Using mapping programs to match seeds collected from a known origin to planting sites based on climatic information
- Identifying and communicating needs for new or different genetic material to seed suppliers or nurseries
- Planting seedlings germinated from seeds collected from various locations throughout a species' native range.

8.2. Favor existing genotypes that are better adapted to future conditions

As populations experience cumulative changes in climate, or short-term extremes in climate, new selective pressures on populations may result in changes in phenotypic expression and genotypic evolution responses (Reed et al. 2011). Some genotypes may be better adapted to future conditions or changing conditions because of pest resistance, broad physiological tolerances, short regeneration times, or other characteristics (Millar et al. 2007, Spittlehouse and Stewart 2003). Identifying and managing these future-adapted genotypes during various life stages may allow a population to persist where it may otherwise fail. However, the use of this approach may be currently limited by the uncertainty about precise future conditions and which genotypes are best suited to these conditions (Breed et al. 2013). It is also possible that genotypes from other sites could interfere with the adaptation of local populations, if the imported resources are not adapted to withstand local pressures (e.g., frost tolerance or pathogen resistance). Availability of source material may also limit the use of this approach.

Examples of adaptation tactics are:

- Planting stock from seeds collected from local trees that exhibit drought tolerance, pest resistance, or other desirable qualities
- Planting stock from seeds collected from healthy trees in warmer or drier locations in the region
- Retaining some survivors of a dieback event, such as drought-induced mortality or pathogenic blight, rather than salvage harvesting all trees in an affected area
- Creating and monitoring areas of natural regeneration in order to identify and promote well-adapted phenotypes
- Planting disease-resistant chestnut in order to reestablish a form of this species on the landscape.

Strategy 9: Facilitate community adjustments through species transitions

Species composition in many forest ecosystems is expected to change as species adapt to a new climate and transition into new communities (Iverson et al. 2004b). This strategy seeks to maintain overall ecosystem function and health by gradually enabling and assisting adaptive transitions of species and communities in suitable locations. This may result in slightly different species assemblages than those present in the current community, or an altogether different community in future decades. This strategy includes aggressive actions to promote ecosystem change rather than an unchanging community or species mix. Many of the approaches in this strategy attempt to mimic natural processes, but may currently be considered unconventional management responses. In particular, some approaches incorporate assisted migration, which remains a challenging and contentious issue (McLachlan et al. 2007, Ricciardi and Simberloff 2009). It is not suggested that managers attempt to introduce new species without thoroughly investigating potential consequences to the native ecosystem (Ricciardi and Simberloff 2009). This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response. Outcomes from early efforts to transition communities can be evaluated to provide both information on future opportunities and specific information related to methods and timing.

Approaches:

9.1. Favor or restore native species that are expected to be adapted to future conditions

There are many cases where native species may be well adapted to the future range of climatic and site conditions (Landscape Change Research Group 2014, Walk et al. 2011). Using management to favor native species in a community or forest type that are expected to fare better under future climate change can facilitate a gradual shift in the forest composition. Establishing or emphasizing future-adapted species now may create opportunities to fill the niche left by species that decline. Where communities are dominated by one or a few species, this approach will probably lead to conversion to a different community type, albeit with native species.

Examples of adaptation tactics are:

- Underplanting a variety of native species on a site to increase overall species richness and provide more options for future management
- Favoring or establishing oak, pine, and other more drought- and heat-tolerant species on narrow ridge tops, south-facing slopes with shallow soils, or other sites that are expected to become warmer and drier
- Seeding or planting drought-resistant genotypes of commercial species (e.g., loblolly pine) where increased drought stress is expected.

9.2. Establish or encourage new mixes of native species

Repeated periods of warming and cooling over the last 15,000 years have resulted in large shifts in species composition (Davis 1983, Jacobson et al. 1987, Shuman et al. 2002). Novel combinations of climatic and site conditions are expected to continue to affect individual species in different ways. Although some species may not occur in a forest or community type as currently defined, they may have been together previously. Novel mixing of native species may lead to the dissolution of traditional community relationships and result in conversion to a newly defined or redefined forest or community type (Davis et al. 2005, Root et al. 2003).

Examples of adaptation tactics are:

- Planting or seeding a mixture of native species currently found in the area that are not typically grown together but may be a suitable combination under future conditions
- Underplanting with eastern white pine to diversify the conifer component of a stand that has had no eastern white pine
- Intensifying site preparation in a northern hardwoods stand to promote the establishment of oak from an adjacent stand
- Allowing a species native to the region (e.g., black locust) to establish where it was not historically present, if it is already encroaching and likely to do well there under future climate conditions.

9.3. Guide changes in species composition at early stages of stand development

Long-term ecosystem function may be jeopardized if existing and newly migrated species fail to regenerate and establish. Active management of understory regeneration may help transition forests to new and better-adapted compositions more quickly by promoting desired species and reducing competition from undesirable, poorly adapted, or invasive species. Natural disturbances often initiate increased seedling development and genetic mixing, and can be used to facilitate adaptation (Joyce et al. 2009). Silvicultural prescriptions can mimic natural disturbance to promote regeneration in the absence of natural disturbance. Under drier conditions and increased stress, promoting regeneration and discouraging competitors may require more-intensive site preparation, including prescribed fire, soil disturbance, and herbicide use. When forests are dominated by one or a few species, this approach may lead to conversion to a different forest type.

Examples of adaptation tactics under this approach are:

- Preventing and removing undesired species, including invasive nonnative or aggressive native species, in order to reduce competition for moisture, nutrients, and light
- Controlling beech suckers, sprouts, and brush by using herbicide or mechanical treatment in areas affected by beech bark disease in order to reduce competition with the regeneration of other species
- Planting or seeding sufficient stocks of desired species before undesirable species have the chance to establish or compete
- Performing timber stand improvement to favor and promote the growth of desirable growing stock.

9.4. Protect future-adapted seedlings and saplings

As climate change increases both direct and indirect stressors on forest ecosystems, it becomes increasingly important to ensure the adequate regeneration of tree species in order to maintain forest or woodland conditions. Seedlings and saplings are generally more sensitive than older growth stages to changes in moisture and temperature, physical disturbance, herbivory, and other stressors (Walck et al. 2011). For this reason, protecting seedlings or saplings of existing or newly migrated species can strongly shape the ways in which communities adapt (The Nature Conservancy 2009). Further, tending regeneration by protecting it from herbivory, removing competition, or otherwise reducing damage to seedlings and saplings helps to promote the transition to desired future conditions and functions.

Examples of adaptation tactics are:

- Using repellent sprays, bud caps, or fencing to prevent browsing on species that are expected to be well adapted to future conditions
- Using tree tops from forest harvest or plantings of nonpalatable tree species as locations for "hiding" desirable species from herbivores to reduce browse pressure
- Preventing and removing undesired species, including invasive nonnative or aggressive native species, in order to reduce competition for moisture, nutrients, and light
- Restricting recreation or management activities that may have the potential to damage regeneration
- Partnering with state wildlife agencies to monitor herbivore populations or reduce populations to appropriate levels.

9.5. Disfavor species that are distinctly maladapted

A species is considered maladapted when its environment changes at a rate beyond the species' ability to adapt and accommodate those changes (Johnston 2009). Species at the southern or highest elevational extent of their geographic range are especially vulnerable to habitat loss, and some of these species are expected to decline rapidly as conditions change (Iverson 2002, Iverson and Prasad 1998). Monitoring or inventory data for some species may already show evidence of decline at a particular site, although their decline may not be attributed to a single cause, but to a combination of causes that may include varying degrees of interaction with climate change. Models that incorporate climate change and species' life history characteristics may identify other species that are likely to decline (Landscape Change Research Group 2014, Wang et al. 2014). Species declines may require rapid and aggressive management responses to maintain forest cover and ecosystem function during periods of transition. In ecosystems where the dominant species are likely to decline substantially or disappear, this may mean dramatically altering the species assemblage through active or passive means.

Examples of adaptation tactics are:

- Removing unhealthy individuals of a declining species in order to promote other species expected to fare better. This does not imply that all individuals should be removed, and healthy individuals of declining species can be retained as legacies.
- Anticipating and managing rapid decline of species with negative prognoses in both the short and long term (e.g., hemlock) by having adequate seed stock of a desired replacement species expected to do well under future climate conditions
- Protecting healthy legacy trees that fail to regenerate while deemphasizing their importance in the mix of species being promoted for regeneration.

9.6. Manage for species and genotypes with wide moisture and temperature tolerances

Inherent scientific uncertainty surrounds climate projections at finer spatial scales (Schiermeier 2010), making it necessary to base decisions upon a wide range of predictions of future climate. Managing for a variety of species and genotypes with a wide range of moisture and temperature tolerances may better distribute risk than attempting to select species with a narrow range of tolerances that are best adapted to a specific set of future climate conditions (The Nature Conservancy 2009).

Examples of adaptation tactics are:

- Favoring species that are currently present that have wide ecological amplitude and can persist under a wide variety of climate and site conditions
- Planting or otherwise promoting species that have a large geographic range, occupy a diversity of site conditions, and are projected to have increases in suitable habitat and productivity
- Promoting long-lived conifers with wide ecological tolerances, such as eastern white pine
- Identifying and promoting species that currently occupy a variety of site conditions and landscape positions.

9.7. Introduce species that are expected to be adapted to future conditions

Maintaining ecosystem function or transitioning to a better-adapted system may involve the active introduction of species or genotypes to areas that they have not historically occupied, often described as assisted migration, assisted colonization, or managed relocation (Hoegh-Guldberg et al. 2008, Hunter 2007, McLachlan et al. 2007, Ricciardi and Simberloff 2009). One type of assisted migration, sometimes called forestry assisted migration, focuses on moving species to new locations in order to maintain forest productivity and health under climate change (Pedlar et al. 2012, Seddon 2010). Given the uncertainty about specific climate conditions in the future, the likelihood of success may be increased by relocating species with a broad range of tolerances (e.g., temperature, moisture) from across a wide range of provenances. This approach is generally considered less risky than species-rescue assisted migration (described in the next section) because it moves species to new habitats within their current range or over relatively short distances outside their current range, and focuses on widespread species for which much is known about their life history traits (Pedlar et al. 2012). However, there are still risks associated with moving any species, such as introducing new pests or diseases, the potential for hybridization with other closely related species, and genetic bottlenecks if the introduced seed source is not adequately diverse (Aubin et al. 2011).

Examples of adaptation tactics are:

- Planting oaks, pines, and other drought-tolerant species on sites within the current range that are expected to become drier and that have not been historically occupied by those species
- Planting flood-tolerant species, such as swamp white oak and silver maple, on sites that are expected to become more prone to flooding and that are currently not occupied by flood-tolerant species
- Planting southern species, such as shortleaf pine, north of its current range on suitable sites based upon its projected range expansion
- Planting disease-resistant cultivars of elm or chestnut where they are likely to have suitable habitat.

9.8. Move at-risk species to locations that are expected to provide habitat

The climate may be changing more rapidly than some species can migrate, and the movement of species may be restricted by land use or other impediments between areas of suitable habitat (Davis and Shaw 2001, Iverson et al. 2004a). This can be particularly challenging for species that are already rare or threatened. Another subset of assisted migration, sometimes called species-rescue assisted migration, focuses on avoiding extinction of species threatened by climate change (Pedlar et al. 2012). If current habitat occupied by those species is expected to become (or already is) unsuitable, assisted migration to potential new suitable habitat may be the best option to ensure survival of the species (Vitt et al. 2010). Because such species are often extremely rare, this type of assisted migration can also potentially cause declines in the donor populations through removal of seeds or individuals (Aubin et al. 2011). This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response (Ricciardi and Simberloff 2009).

Examples of adaptation tactics are:

- Planting or seeding a rare or threatened plant species that is at risk for extinction to a newly suitable habitat outside its current range
- Assisting the migration of wildlife around barriers from low elevations to higher elevations by trapping and releasing in newly suitable locations
- Moving plants or animals from a mountaintop to another mountaintop north of their current range.

Strategy 10: Realign ecosystems after disturbance

Ecosystems may face significant impacts as a result of climate change-related alterations in disturbances, including fire, drought, invasive species, and severe weather events (Dale et al. 2001). Disturbances are primary drivers of many ecosystems, but changes in the frequency, intensity, and duration of disturbance events may create significant management challenges (Lawler 2009). Although it is often not possible to predict a disturbance event, it is possible to increase overall preparedness for large and severe disturbances and prioritize rapid response. Many of the best opportunities for addressing disturbance-related impacts may occur immediately after the disturbance event; having a suite of preplanned options in place may facilitate an earlier and more flexible response and prevent maladaptive responses. In the future there are likely to be more frequent situations where a disturbance exceeds the resilience of an ecosystem, such that even intensive management may be insufficient to return the ecosystem to a prior condition. In these cases, it may be necessary to reevaluate and adjust management goals, which can involve realigning the ecosystem to better match new climate and environmental conditions (Millar et al. 2007). This strategy involves consideration of the full range of potential impacts and planning to respond to severe ecosystem disturbance and disruption.

Approaches:

10.1. Promptly revegetate sites after disturbance

Potential increases in the frequency, intensity, and extent of large and severe disturbances may disrupt regeneration and result in loss of forest cover, productivity, or function in the long term. Changing conditions are expected to threaten regeneration processes for some species, and may result in failure of natural regeneration of desired species. Prompt revegetation of sites following disturbance helps reduce soil loss and erosion, maintain water quality, and discourage invasive species in the newly exposed areas. These efforts can also provide an intervention point for promoting species and systems that may be better adapted to future conditions.

Examples of adaptation tactics are:

- Planting a variety of future-adapted species during revegetation efforts to ensure diverse regeneration and provide options for future management
- Creating suitable physical conditions for natural regeneration through site preparation (e.g., chaining after a burn to promote seed establishment)
- Monitoring areas of natural regeneration on a more frequent basis, and prioritizing planting or seeding where natural regeneration is slow to succeed
- Coordinating with the public and other organizations to avoid conflicting or misguided responses.

10.2. Allow for areas of natural regeneration to test for future-adapted species

Although many areas may be replanted after severe disturbance, some areas can be set aside to allow for natural regeneration as a means to identify the well-adapted species and populations (Joyce et al. 2009). The use and monitoring of test or “control” areas of natural revegetation following disturbance may help managers identify (1) species that are well adapted to the changing climate and environmental conditions and (2) potential threats in the form of invasive species or poor regeneration of desirable species.

Examples of adaptation tactics are:

- Using modeling and remote sensing to identify areas at low risk for erosion, flooding, or other threats that could be set aside for natural regeneration
- Monitoring naturally revegetated areas for changes in species composition, productivity, and other factors
- Controlling competition from undesirable tree species and invasive species to enhance regeneration of desired tree species
- Removing small-diameter residual trees to reduce competition, increase sunlight, and improve seed germination potential
- Creating conditions that will be favorable for regeneration of desired species, for example by removing the duff layer to allow germination and sprouting of shortleaf pine.

10.3. Realign significantly disrupted ecosystems to meet expected future conditions

Some ecosystems may experience such significant disruption and decline that desired conditions or management objectives appear to be no longer feasible. This situation may occur if most species in the ecosystem are projected to decline as climate changes. Management of these systems may be adjusted to create necessary changes in species composition and structure to better adapt forests to current and anticipated environments, rather than to historical predisturbance conditions (Millar et al. 2007, Spittlehouse and Stewart 2003). Developing clear plans that establish processes for realigning significantly altered ecosystems before engaging in active management will allow for more thoughtful discussion and better coordination with other adaptation responses.

Examples of adaptation tactics are:

- Allowing a transition in forest type by planting future-adapted species within a stand that is already declining or is expected to decline (e.g., planting jack pine and tamarack in a failing white spruce stand, or underplanting eastern white pine in the next regeneration cut of quaking aspen)
- Planting species expected to be better adapted to future conditions, especially where natural regeneration in forests affected by disturbance is widely failing
- Allowing nonnative invasive or aggressive native species to remain as part of a novel mix of species, rather than eradicating these species
- Creating novel communities “from scratch” in areas that have been severely affected by natural or human disturbance as part of intensive remediation efforts.

CHAPTER 4. Urban Forest Adaptation Strategies and Approaches

Forest management spans a continuum of forests, from closed-canopy forests to more open woodlands and savannas and barrens, and also includes the management of urban forests. Urban forests are an integral aspect of **green infrastructure**, which can be defined as "an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to human populations" (Benedict and McMahon 2006: 5). Urban forests include more developed "urban" sites such as street and yard trees, parks, cemeteries, school grounds, corporate campuses, and unmanaged green spaces, as well as more "natural" areas such as forest preserves and larger urban parks. The vitality and interconnectedness of these urban forests are critical for many landscape-scale ecological processes (such as migration, pollination, and carbon sequestration) and the long-term ecological function of urban landscapes (Rudnick et al. 2012). This chapter puts the adaptation strategies, approaches, and tactics laid out in the previous chapter into an urban context by recognizing the unique pressures placed upon urban forests, such as pollution, restricted rooting conditions, and altered soils (Box 12).

This chapter is organized in a similar manner to the previous chapter, with broad strategies linked to more specific approaches and tactics. The 10 adaptation strategies are generally arranged to start with ideas that focus on **resistance** adaptation options and continue on to ideas that focus more on **transition**, although this arrangement does not indicate preference or priority (Chapter 3). Approaches are still broad enough that managers will need to evaluate and tailor them to meet individual management goals. Not all approaches can or should be used in every location or situation. Tactics are prescriptive actions with specific site conditions and objectives in mind.

Input and feedback on the urban strategies and approaches in this chapter came from more than 35 members of the Chicago Wilderness[1] Climate Change Task Force and Trees and Green Infrastructure Task Force. The lead authors and other contributors to this chapter are listed in Appendix 3. Members of the task forces include professionals in the fields of forest ecology, climate change ecology, urban forestry, soil science, urban land management, urban ecology, wildlife management, ecological restoration, and hydrology. The Chicago Wilderness team also provided generalized examples of tactics to highlight some possible ways in which each approach may be applied in urban forests.

The menu of tiered urban forestry adaptation actions (Box 12) provides practical, relevant concepts that can be incorporated into planning and decisionmaking. The menu is intended to be used in conjunction with the Adaptation Workbook (Chapter 5). The example tactics that are provided for each adaptation approach are not meant to be implemented directly; rather, they are meant to provide a sense of how managers could develop specific tactics for their management goals and site conditions. Additionally, although the urban adaptation strategies and approaches were designed to directly assist managers, many adaptation actions will require or benefit greatly from planning, education and outreach, research, or changes in policy or infrastructure (Box 13).

[1] Chicago Wilderness is a regional alliance of more than 300 nonprofit and Corporate Council member organizations that work together to restore local nature and improve the quality of life for all living things by protecting the lands and waters on which we all depend. Learn more at www.chicagowilderness.org.

Box 12

Urban Forest Adaptation Strategies and Approaches

Strategy 1. Sustain or restore fundamental ecological functions.

1.1. Maintain or restore soils and nutrient cycling in urban areas.
1.2. Maintain or restore hydrology.
1.3. Maintain or restore riparian areas.
1.4. Reduce competition for moisture, nutrients, and light.
1.5. Restore or maintain fire in fire-adapted ecosystems.

Strategy 2. Reduce the impact of biological stressors.

2.1. Maintain or improve the ability of forests to resist pests and pathogens.
2.2. Prevent the introduction and establishment of invasive plants and remove existing invasive species.
2.3. Manage herbivory to promote regeneration, growth, and form of desired species.

Strategy 3. Reduce the risk and long-term impacts of severe disturbances.

3.1. Alter forest structure or composition to reduce risk or severity of wildfire.
3.2. Maintain trees and remove hazards to reduce severity or extent of wind and ice damage.

Strategy 4. Maintain or create refugia.

4.1. Prioritize, maintain, and restore unique sites.
4.2. Prioritize and maintain sensitive or at-risk species or communities.
4.3. Establish artificial reserves for at-risk and displaced species.

Strategy 5. Maintain and enhance species and structural diversity.

5.1. Promote diverse age structure.
5.2. Maintain and restore diversity of native species.
5.3. Retain biological legacies.
5.4. Establish reserves to maintain ecosystem diversity.

Strategy 6. Increase ecosystem redundancy across the landscape.

6.1. Manage habitats over a range of sites and conditions.
6.2. Expand or buffer the boundaries of reserves to increase diversity.

Strategy 7. Promote landscape connectivity.

7.1. Reduce landscape fragmentation.
7.2. Maintain and create habitat corridors through reforestation or restoration.

Strategy 8. Maintain and enhance genetic diversity.

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range.
8.2. Favor existing genotypes that are better adapted to future conditions.
8.3. Use new genotypes that are better adapted to future threats and conditions.

Strategy 9. Facilitate composition adjustments through species transitions.

9.1. Favor or restore native species that are expected to be adapted to future conditions.
9.2. Establish or encourage new mixes of native species.
9.3. Select tree species to match current and future site conditions.
9.4. Protect future-adapted seedlings and saplings.
9.5. Disfavor species that are distinctly maladapted.
9.6. Manage for species or genotypes with wide moisture and temperature tolerances.
9.7. Introduce species that are expected to be adapted to future conditions.
9.8. Move at-risk species to locations that are expected to provide habitat.

Strategy 10. Realign urban ecosystems after disturbance.

10.1. Promptly revegetate sites after disturbance.
10.2. Prioritize remediation of remaining trees following disturbance.
10.3. Realign significantly disrupted ecosystems to meet expected future conditions.

Box 13

Adaptation Strategies for Planning and Policy

The Adaptation Strategies and Approaches for land managers have been designed for implementation by land managers and project planning teams. However, some strategies and approaches require (or are facilitated by) planning, education and outreach, research, or changes in policy or infrastructure. Some of the most applicable strategies and approaches that fall into this area are listed below:

- Limiting use of known invaders in horticultural plantings in and around natural areas through partnerships with homeowners, municipalities, and park districts
- Working with local nurseries and growers' associations to draw attention to potential impacts and offer alternative species to those that may be potentially harmful or invasive
- Promoting at-risk species currently used in the horticultural trade and developing sources and markets for additional at-risk species where appropriate, especially southern species at the northern edge of their range
- Developing cultivars of native tree species that are well adapted to different (or a variety of) urban sites, working with nurseries and retailers to make them readily available, and promoting their use in urban plantings
- Prioritizing creation of new parks, easements, or natural areas centered on areas that have high levels of biological legacies.

Urban Adaptation Strategies and Approaches

Strategy 1: Sustain or restore fundamental ecological functions

The changing climate may alter the complex interactions among climate, vegetation, and landforms, resulting in changes in hydrology, soil quality, and nutrient cycling. Urban areas often involve further complications because of the greater likelihood that human activities have already significantly altered ecosystem functioning and will continue to do so. Urban conditions are often characterized by difficult growing conditions, including impermeable surfaces, air and water pollution, frequent human interaction, and small soil volumes. Existing guidelines and best management practices for forest management describe actions that can be used to reduce or reverse impacts to soil and water. Many of these actions are also likely to be beneficial in the context of adaptation, although additional effort may be required to maintain ecosystem function in urban areas.

Approaches:

1.1. Maintain or restore soils and nutrient cycling in urban areas

Most urban tree problems are related to poor soils or growing conditions (Patterson and Mader 1982), which could exacerbate stresses induced by climate change. Urban soils are often highly disturbed, lack essential nutrients, and commonly include detrimental elements such as chemicals, concrete, asphalt, and other foreign matter that limit the long-term viability of a tree. Trees are dependent on adequate soil characteristics such as rooting volume, organic matter content, drainage capacity, and nutrient availability to achieve healthy maturity. Prior to planting a tree, soil and site analyses can be conducted to determine if the soil content, texture, or volume would meet the long-term needs of a growing healthy tree.

Examples of adaptation tactics are:

Urban natural areas

- Removing invasive species that have negative impacts on soil processes or undesirable feedbacks to nutrient inputs (e.g., European buckthorn; Heneghan et al. 2006)
- Adding organic soil amendments (e.g., mulch, biochar) to urban sites undergoing restoration or revegetation.

Developed urban sites

- Providing and developing adequate soil volume, texture, structure, and organic matter to support healthy tree growth (e.g., Watson and Himelick 2013)
- Removing and replacing the soil if toxicity or chemical levels are too high
- Amending soil with organic or structural material to improve drainage, pH, and rooting
- Installing a layer of mulch over the root zone of the tree to help retain moisture and mimic a natural growing environment.

1.2. Maintain or restore hydrology

Changes in climate may increase runoff during heavy storm events in some areas. Impermeable surfaces are more common in the urban setting and direct water into water bodies through storm sewers. Stormwater thus bypasses vegetation and other natural features that could slow water flow and reduce pollution. Vegetation and associated ecosystem features can filter, intercept, and absorb stormwater, reducing runoff and improving the quality of water reaching streams and lakes. Water is intercepted by the tree canopy and held by the root systems of herbaceous and woody plants and associated soil organic material. In highly developed areas where large areas of vegetation are not feasible, engineered features can also be used to increase permeability and help redistribute water.

Examples of adaptation tactics are:

Urban natural areas

- Restoring natural hydrology where appropriate by removing drain tiles or other remnant hydrological modifications
- Restoring native communities and ecosystem components (e.g., natural groundcover, litter layer, coarse woody debris) in riparian areas
- Adjusting trail location and design to minimize erosion under more intense surface runoff.

Developed urban sites

- Directing runoff into natural features with herbaceous and woody plant cover to reduce runoff and nonpoint source pollution, while still providing outflow for excess water
- Connecting natural features such as planting beds, bioswales, rain gardens, and sequential stormwater treatments to other natural systems
- Using permeable paving, suspended surfaces, or Silva Cells (Deeproot Green Infrastructure, San Francisco, CA) to enable runoff to collect and water trees.

1.3. Maintain or restore riparian areas

Much of the forest cover in urban regions is located in riparian areas. Forests located within riparian areas serve important ecosystem functions, such as decreasing soil erosion, filtering water, and storing and recycling organic matter and nutrients (Barling and Moore 1994, Brandt et al. 2012, Castelle et al. 1994). Trees in riparian areas also provide shade, which helps to buffer stream temperatures. Forested riparian areas can serve as corridors for wildlife and plant species migrating across otherwise fragmented landscapes (Heller and Zavaleta 2009). The use of protective guidelines, such as best management practices and riparian management zones, can help to prevent damage to riparian areas during management activities.

Examples of adaptation tactics are:

Urban natural areas

- Restoring or promoting a diversity of tree and plant species in order to increase stream shading, provide a source of woody debris, stabilize the soil, and provide habitat and connectivity for wildlife
- Restoring or reforesting riparian areas adjacent to developed areas in order to reduce erosion and nutrient loading into adjacent water bodies

- Managing water levels to supply proper soil moisture to vegetation adjacent to the stream during critical time periods, either by manipulation of existing dams and water control structures or restoration of natural dynamic water fluctuations.

Developed urban sites

- Reclaiming developed sites and restoring or reforesting riparian areas in order to reduce erosion and nutrient loading into adjacent water bodies.

1.4. Reduce competition for moisture, nutrients, and light

Climate change will alter competitive dynamics among species and is likely to result in changes in species composition and mortality patterns. Reducing competition for resources can enhance the persistence of desired species and increase the ability of ecosystems to cope with the direct and indirect effects of climate change (Dwyer et al. 2010, Evans and Perschel 2009).

Examples of adaptation tactics are:

Urban natural areas

- Managing buffer areas adjoining natural sites to limit potential impacts from invasive species that could have an adverse competitive impact on existing species
- Selecting species that will be strong competitors on restored or reclaimed sites.

Developed urban sites

- Removing mowed turf from the rooting zone of trees and replacing it with organic mulch or other plants that require lower water and nutrient inputs
- Removing nonnative invasive species to reduce competition, and to improve native species diversity.

1.5. Restore or maintain fire in fire-adapted ecosystems

Fire management can be difficult in urban settings due to potential impacts to the built environment and public health. Where possible, fire can be an important management strategy in supporting ecosystem function and resilience. Where ecological or social constraints limit the application of prescribed fire, alternative management strategies (i.e., fire surrogates) can provide similar benefits.

Examples of adaptation tactics are:

Urban natural areas

- Using prescribed fire to maintain fire-adapted ecosystems and reduce risk of fire spread into the wildland-urban interface
- Using prescribed fire during suitable conditions (periods of low air pollution, low winds, low temperatures) to avoid negative impacts and potential for unwanted spread
- Incorporating understory thinning, mowing, or other fire surrogate strategies to support native ecosystems where fire management is not possible.

Developed urban sites

- Managing fire-adapted urban trees and ecosystems using fire-surrogate treatments such as mowing, hand weeding, and applying herbicide.

Strategy 2: Reduce the impact of biological stressors

Climate change may result in increases in biological stressors such as pests, pathogens, and invasive plant species. Urban areas are especially prone to attacks by nonnative pests and pathogens. Pests that are currently limited by cold temperatures or growing season (e.g., hemlock woolly adelgid in New England) could also affect urban areas sooner than surrounding rural areas due to the effects of the urban heat island. Reducing or eliminating stressors that might make a tree more susceptible to new or existing pests or pathogens will be important to maintaining forests in urban areas (Urban 2008).

Approaches:

2.1. Maintain or improve the ability of forests to resist pests and pathogens

Many forest pests and pathogens are expected to expand or shift their ranges under climate change, and climate change may also increase the susceptibility of urban forests to damage from pests and pathogens through increased stress. Avoiding the introduction of pests is often not possible, but certain tactics may increase resistance of trees and forests to these stressors. The tactics are similar to those outlined for nonurban forests. The primary difference is likely to be a much greater ability and incentive to manage individual trees in urban forests.

Examples of adaptation tactics are:

Developed urban sites

- Selecting species and cultivars that are less susceptible to pests and pathogens
- Treating susceptible trees with pesticides and fungicides when appropriate and feasible.

All urban sites

- Promoting diversity across taxonomic levels by reducing the concentration of any one genus, species, or cultivar in order to reduce the risk from a selective pest or pathogen
- Increasing age diversity to help avoid large concentrations of declining trees that may be more susceptible to certain pests or pathogens
- Monitoring for new invaders so action can be taken before the pest or pathogen becomes established
- Encouraging the use of best management practices that limit the spread or level of damage caused by pests or pathogens
- Participating in a rapid response system for pest and pathogen detection including training volunteers and local organizations to assist with identifying pests and pathogens.

2.2. Prevent the introduction and establishment of invasive plants and remove existing invasive species

Climate change is likely to increase the rate of spread of invasive species (Chornesky et al. 2005, Millar et al. 2007). Early detection and rapid response will be very important as opportunities for new invaders increase. Urban areas are especially susceptible to introduction and spread of invasives because of horticultural practices, nutrient loading, high levels of disturbance, and moderated microclimate.

Examples of adaptation tactics are:

Urban natural areas

- Managing and monitoring natural area buffers to limit access of invasive plants to high-quality areas
- Limiting the spread of invasive species introduced through recreational activities (e.g., boot brushes at trailheads).

All urban sites

- Responding rapidly with stewards and volunteers to limit the spread of invasive species upon introduction
- Limiting use of known invaders in horticultural plantings (especially in and around natural areas) through partnerships with homeowners, municipalities, and park districts
- Training local land managers, landowners, volunteers, and organizations to recognize possible threats and to report them to appropriate agencies such as the U.S. Department of Agriculture or Cooperative Weed Management Areas
- Working with local resources such as master gardener programs to educate the public about potential impacts and how to report them to the appropriate agencies.

2.3. Manage herbivory to promote regeneration, growth, and form of desired species

Urban areas can be heavily populated with mammalian herbivores such as rabbits and deer. These herbivores can hinder regeneration and growth of desired plant species, and populations of some herbivorous species may grow in some areas as winters become less severe. Protecting desired species from herbivory has the obvious benefit of directly reducing grazing damage, but can also be important in fostering resilience to other stressors, which are expected to be exacerbated by climate change. This approach may be combined with other approaches that release advance regeneration or stimulate new regeneration.

Examples of adaptation tactics are:

All urban sites

- Applying repellant or installing fences, bud caps, and other physical barriers to prevent herbivory
- Promoting abundant regeneration of multiple species in order to supply more browse than herbivores are expected to consume.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances

Climate change may increase the likelihood and risk of severe disturbances, which will have significant effects on urban trees. Urban tree failures can cause severe property damage, electric outages (Simpson and Van Bossuyt 1996), and injuries or fatalities to human beings. From 1995 to 2007, there were 407 tree-related human fatalities in the United States (Schmindlin 2009). In developed urban sites, these potential impacts make it essential for risk to be managed at the individual tree level. Factors such as tree form, size, condition, species, wind speed, pruning, and wood material properties affect tree resistance to storm damage (Duryea et al. 2007, Francis 2000, King 1986, Putz et al. 1983). Urban foresters must balance the risk of tree failure, including the danger to people and property, with the loss of benefits when shade trees are removed. This is especially important for large trees, which provide greater benefits and take a long time to replace (Miller 1997). Priorities are somewhat different in urban natural areas, where avoiding risk is more associated with minimizing disturbances that are potentially devastating to tree communities, especially those that could affect urban populations and the built environment (e.g., fires spreading from natural areas).

Approaches:

3.1. Alter forest structure or composition to reduce risk or severity of wildfire

Risk of wildfire is likely to increase in urban natural areas in much the same fashion as in nonurban forests. However, due to their location in the wildland-urban interface, these areas are of especially high priority in risk reduction. Developed landscapes in the wildland-urban interface may incorporate somewhat different principles of risk reduction through altering forest structure and composition, such as the Firewise methods of creating defensible space around structures and using less-combustible landscaping (see http://www.firewise.org).

Examples of adaptation tactics are:

Urban natural areas

- Using prescribed fire (where possible) or fire-surrogate treatments to manage the woody understory to reduce the risk of catastrophic wildfire
- Cooperating with and training municipal firefighting authorities to respond quickly and appropriately to fires in natural areas.

Developed urban sites

- Avoiding highly flammable species in plantings near natural areas
- Avoiding the use of highly flammable landscape materials (e.g., pine straw, shredded bark mulch) near buildings located near natural areas.

3.2. Maintain trees and remove hazards to reduce severity or extent of wind and ice damage

Storm damage from wind and ice can be particularly problematic in urban areas because of the risk to life and property, and both could become more severe because of changes in climate. When an urban forest undergoes severe disturbances such as strong wind and ice storms, downed limbs and trees can result in loss of electric service, displacement of families and businesses, and blockage of emergency vehicles. Structural pruning can mitigate these safety and infrastructure issues by fostering mechanically strong branch structure (American National Standards Institute 2008). Although intensive hazard management is common in developed areas, it may also take place in urban natural areas where individual tree management is necessary or possible, such as in high-use areas or near infrastructure. Even when trees are maintained, however, some limb and tree failure can occur. Promptly removing these hazards can help mitigate the severity of the disturbance and associated negative public reaction.

Examples of adaptation tactics are:

Urban natural areas

- Monitoring for hazard trees near the stand edge and removing them if there is a target (e.g., a playground, hiking paths, or road) present
- "Softening" stand edges (i.e., reducing the edge influence at regenerating edges and minimizing abrupt transitions) to reduce susceptibility to wind damage.

Developed urban sites

- Maintaining trees on a regular pruning cycle and using American National Standards Institute A300 (2008) standards and best management practices as guidelines for tree care and maintenance
- Removing hazard trees as quickly as possible.

Strategy 4: Maintain or create refugia

Refugia are areas that have resisted ecological and climatic changes occurring elsewhere; these areas often provide suitable habitat for relict populations of species that were previously more widespread (Keppel et al. 2012, Millar et al. 2007). Despite their rarity in urban areas, refugia can still be important for species of conservation concern. For many taxa, they may offer the best chances for survival under climate change. Identification of refugia is an important first step toward their conservation under climate change in urban areas (Keppel et al. 2012).

Approaches:

4.1. Prioritize, maintain, and restore unique sites

In urban areas, many forests and natural ecosystems have been degraded or developed into other land uses. As a result, forest ecosystems are relatively uncommon on the landscape and may already act as refugia by providing habitat for species lost from surrounding areas due to human-caused disturbance. Sites may be of particular interest for one or more reasons. They may currently support high levels of biodiversity. They may contain a diverse range of geophysical diversity that is likely to sustain and promote species diversity over the long term. Or they may have a combination of high biological and geophysical diversity. Sites with several topographically related microclimates and local permeability may provide the best chance for species responding to climate change (Anderson et al. 2012). Restoration or reclamation projects may be needed to increase the representation of these habitats on the landscape.

Examples of adaptation tactics are:

Urban natural areas

- Protecting existing habitat remnants from disturbance, particularly if they are in areas that may provide future climate refugia
- Restoring unique habitats that may be less susceptible to climate change or using reclamation efforts to create new patches of such habitats on suitable sites
- Identifying and protecting areas of high geophysical or topographic diversity with the expectation that these areas may provide a range of climatic options to species with diverse requirements.

Developed urban sites

- Identifying urban plantings that could serve as refugia.

4.2. Prioritize and maintain sensitive or at-risk species or communities

Maintenance of sensitive and at-risk species or communities in situ as long as possible could help the species or communities persist until new long-term sites can be located and populated. Restoring and protecting historical remnant areas of ecologically significant species or communities may be helpful in some urban natural areas. More developed urban areas often contain engineered habitats for a variety of native and nonnative species, and can also play an important role in providing habitat. Artificial reserves are addressed in approach 4.3.

Examples of adaptation tactics are:

Urban natural areas

- Maintaining species and structural elements that provide habitat for at-risk species
- Increasing buffer areas to protect at-risk communities from disturbance and invasion
- Rerouting roads or trails away from at-risk communities in order to reduce damage from traffic or reduce the risk of invasive species introduction.

Developed urban sites

- Establishing and supporting development and management ordinances and regulations that protect and reduce impacts to high-quality remnants and features.

4.3. Establish artificial reserves for at-risk and displaced species

At-risk species are often incorporated into urban reserves (botanical gardens, arboretums, and municipal parks) and urban plantings (e.g., street trees, backyard gardens), and could in some cases be included in restoration or reclamation projects (e.g., urban riverways). Some uncommon to rare tree species, such as Kentucky coffeetree, blue ash, and American yellowwood, are already included in some urban plantings. Additional at-risk species (or species that provide habitat for at-risk species) could be added to urban planting lists to increase their representation in the landscape. Providing new artificial habitat for at-risk species could help sustain them under climate change.

Examples of adaptation tactics are:

Urban natural areas

- Collecting seeds and other genetic material of at-risk species to contribute to a genetic repository
- Including at-risk species (or habitat for at-risk species) in restoration or reclamation projects
- Planting individuals in a protected location that is expected to provide suitable habitat into the future in a natural setting, such as a stand on a partner's property.

Developed urban sites

- Using local conservatories, arboretums, botanical gardens, and parks to cultivate species after climate change makes natural regeneration challenging for that species
- Including at-risk species (or species that provide habitat for at-risk wildlife) in urban park, street, or campus plantings whenever possible or feasible (e.g., planting endangered southern species in parks).

Strategy 5: Maintain and enhance species and structural diversity

Promoting species and structural diversity is as important in urban forests as in nonurbanized forest landscapes, if not more so. Urban areas are highly susceptible to introduction of nonnative pests and pathogens and often exhibit high occurrence of invasive plant species (Dreistadt et al. 1990, McKinney 2002). Urban forests have been decimated because of a lack of species diversity in the face of pest introductions (Poland and McCullough 2006, Santamour 2004). Widespread acknowledgment of this problem has led to guidelines focused on diversification of the urban forest (Santamour 2004). However, urban areas contain difficult sites, and only a limited set of tree species may be able to tolerate the conditions of many of these sites (Whitlow and Bassuk 1987). Species and structural diversity are especially important as a climate adaptation strategy because urban habitats (both natural areas and urban land uses) are likely to be stressed in the future in many ways, some of which will be unforeseeable (Gill et al. 2007, Kirshen et al. 2008). A diverse set of species, carefully selected to match the urban environment, will be more likely to maintain adequate forest cover and ecosystem services under a changing and increasingly variable climate.

Approaches:

5.1. Promote diverse age structure

A diverse age structure can be beneficial because trees are most vulnerable to specific stressors at different ages. For example, droughts are typically more damaging to seedlings than to mature trees, whereas older individuals may be more susceptible to damage from wind events. In many cases, urban forests are dominated by trees that persisted on the landscape as it became urbanized, and many of these trees are reaching the end of their lifespan (Fahey et al. 2012). Active management may be necessary to promote regeneration and development of younger age classes. Furthermore, in developed urban areas, managers often focus on individual trees, which are removed upon death or damage and replanted as soon as resources permit. Age class diversification may consequently be less straightforward than in natural forests. However, a diverse age structure in these locations could increase the habitat value of the urban forest and spread out tree losses from natural mortality (Clark et al. 1997, Millar et al. 2007). In developed urban sites, some planting and tree removal practices could help develop a more diverse tree age structure both within and among management units.

Examples of adaptation tactics are:

Urban natural areas

- Using group selection to promote multiaged forest stands
- Restoring or creating conditions that allow tree seedlings to thrive by removing nonnative species in the shrub layer and canopy trees.

Developed urban sites

- Planting replacement trees in anticipation of mortality from emerald ash borer and before actual loss of canopy trees in order to diversify age structures
- Rotating planting schedules so that removal and replanting is dispersed geographically, thereby avoiding complete removal or planting within a single area (e.g., street or park) during a single year.

5.2. Maintain and restore diversity of native species

The reasoning and tactics for promoting native species diversity in urban natural areas are essentially the same as those for nonurban forests—that is, diverse communities may be less vulnerable to climate change impacts because risk is distributed among multiple species. The need for and difficulty of promoting native species diversity in urban systems may be greater, however, because of higher pressure from nonnative invasive species and more-extensive planting and promotion of nonnative species (McKinney 2002). Transitioning the urban forest to higher dominance by a diversity of native species would have multiple important positive effects on the adaptation potential of the urban ecosystem (Clark et al. 1997). Native species planted in urban locations can provide important habitat value for wildlife species; areas such as parks may be able to emulate a functioning ecosystem to some degree and support functioning food webs (Marzluff et al. 2001, Nowak and Dwyer 2007). These ecosystems may also be able to provide migration corridors through intensely fragmented urban landscapes (also see strategy 8) (Savard et al. 2000).

Examples of adaptation tactics are:

Urban natural areas

- Restoring or creating conditions that allow for successful regeneration of a diverse mix of native species, such as removing older native and nonnative trees to open the canopy
- Planting desired native species within an area that is otherwise expected to regenerate naturally in order to add diversity.

Developed urban sites

- Promoting native tree species in urban tree planting lists, especially those with high habitat value for wildlife species (e.g., oaks) (Clark et al. 1997)
- Using native plant species as groundcover or horticultural plantings in the rooting zone of urban trees

- Planting species with diverse timing of phenological events (e.g., flowering, fruiting, leaf out, leaf drop) to provide necessary resources over a longer time frame to forest-dependent wildlife species (Walther et al. 2002).

5.3. Retain biological legacies

In urban areas, pre-urban legacy trees often provide much of the ecosystem services and functional value (e.g., carbon storage, shading, and habitat) of the urban forest (Fahey et al. 2012). Preservation of these features will be essential to adapting the urban forest to future climates, because old trees may have superior genetics and they may play a valuable role in helping species persist on the landscape (Gunn 2009). Tactics for urban areas may differ from those used in rural forests managed for timber because there is rarely pressure to harvest or salvage in urban areas. However, legacy retention is often difficult or impossible because of development pressure. Despite the challenge, the retention of legacy trees can be helpful to promote the habitat value that these features provide.

Examples of adaptation tactics are:

Urban natural areas

- Retaining snags and downed trees whenever possible (i.e., those that pose no threat to people or infrastructure) during post-disturbance cleanup operations
- Prioritizing creation of new parks, easements, or natural areas centered on areas that have biological legacies.

Developed urban sites

- Retaining legacy trees from the pre-urban landscape during development or redesign of urban areas
- Retaining snags within parks where they are unlikely to pose a risk to the public in order to provide wildlife habitat.

5.4. Establish reserves to maintain ecosystem diversity

Although urban areas are highly developed, some natural areas may remain to serve as reserves. Reserves are traditionally defined as natural areas with little to no harvest activity that do not exclude management of fire or other natural disturbance processes (Halpin 1997). In a highly fragmented urban area, this definition may need to be adjusted to reflect the realities of what is possible on small tracts of land surrounded by development.

Examples of adaptation tactics are:

Urban natural areas

- Identifying areas with high diversity (species, topography, soils, or other factors) or other desirable attributes that can be set aside as a reserve, perhaps using easements or similar tools
- Prioritizing protection of areas where riparian corridors connect core areas to other reserves and habitats.

Strategy 6: Increase ecosystem redundancy across the landscape

Urbanized landscapes are expected to undergo especially intense alteration of environmental conditions with future climate change (McCarthy et al. 2010). Increasing the number, extent, and representation across land uses and ownerships of a variety of ecosystem types will help to make the persistence of these ecosystem types more likely. Collaboration among an especially wide variety of stakeholders will be necessary to promote this strategy in urbanized landscapes.

Approaches:

6.1. Manage habitats over a range of sites and conditions

Climate change impacts on ecosystems are likely to differ greatly depending on position within the urban-rural gradient, specific land use, and ownership and management type (Iakovoglou et al. 2001, McDonnell et al. 2008). Creating diverse combinations of topographic position, land use, and ownership for each ecosystem type may provide more opportunity for one of those locations to be buffered from change because of the unique site conditions (Colding 2007, Millar et al. 2007). Increasing the number of existing preserved habitats and ecosystems represented in urban landscapes is likely to be difficult (although not necessarily impossible) as most land in urban areas already has a designated land use and most undeveloped ecosystems are already in reserve systems. However, many urban areas have significant levels of land abandonment; restoration and reclamation efforts in these locations could be targeted to produce a diversity of ecosystems and habitats across the landscape (Colding 2007).

Examples of adaptation tactics are:

Urban natural areas

- Restoring native communities that are underrepresented in the landscape, taking advantage of a variety of different landscape positions, ownerships, and other site factors
- Managing for multiple ecosystems and communities within larger natural areas—but without reducing potential habitat patch size.

Developed urban sites

- Managing for underrepresented species, communities, and ecosystems in urban habitats (especially sites such as parks and institutional campuses) to offset potential losses elsewhere (e.g., small areas of wetland habitat within developed areas)
- Seeking and building opportunities for collaboration to connect species, communities, and ecosystems at a larger scale, such as intergovernmental agreements or ordinances.

6.2. Expand or buffer the boundaries of reserves to increase diversity

Reserve expansion can help buffer forest interior habitats from a variety of edge effects, such as changing temperature and moisture conditions and increased exposure to disturbances (Hobbs 2002). Providing buffering from edge effects may be especially important in the harsh environment of the urban landscape. Buffer functions can include benefits such as reduced direct runoff exposure, reduced weed pressure (if weeds are managed in the buffer), and stabilization of banks next to flowing water. These benefits may become increasingly important as climate-related stresses increase on forest interior habitats. However, reserve expansion is often extremely difficult and costly in urban areas so buffering through management practices in urban habitats and creation of easements are likely to be necessary (Rissman et al. 2007).

Examples of adaptation tactics are:

Urban natural areas

- Expanding urban natural areas or developing easements in or adjacent to areas of underrepresented habitat whenever feasible to create buffers (e.g., create streamside buffers, purchase adjacent land, limit roadside damage to the edges of properties)
- Restoring or managing newly acquired reserve or easement areas to promote habitat diversity.

Developed urban sites

- Managing urban areas adjacent to natural areas to create buffer or transitional habitats, by either mimicking the natural habitat to whatever extent possible or mimicking a transitional habitat (e.g., using parks as "savanna-like" edge to forested natural area).

Strategy 7: Promote landscape connectivity

Minimizing fragmentation and maximizing connectivity are both important as adaptation tools in connecting urban areas to the larger landscape. Species migrations and gene flow are essential in climate-mediated species range shifts. Urban areas dominate some of the most important coastal migration corridors in the northeastern United States. To maintain these areas as migration and dispersal corridors in the future, it will be important to minimize additional fragmentation, manage existing corridors to provide high-quality migration habitat, and create new corridors to connect reserves or fragmented habitat in urban areas.

Approaches:

7.1. Reduce landscape fragmentation

Development pressure will probably continue to increase the level of fragmentation on the landscape in most urban areas. Avoiding fragmentation of the few remaining large parcels will instead be the likely emphasis. For example, in the Chicago, IL, region most remaining forested parcels are less than 100 acres in area and many of the remaining units are privately owned or span multiple landowners and uses (Fahey et al. 2015). Therefore, limiting fragmentation in urban areas like Chicago will be most effective with cooperation from a spectrum of the landowners in the region.

Examples of adaptation tactics are:

Urban natural areas

- Establishing partnerships and coordinating acquisition of conserved forest lands or riparian areas to achieve common management goals
- Acquiring property for preserves or creating easements on private landholdings adjacent or close to existing natural areas.

Developed urban sites

- Managing areas adjacent to natural areas to mimic the habitat and ecosystem structure of the natural areas to create larger areas of habitat that are unfragmented in some respects (e.g., continuous canopy cover in residential areas adjacent to a natural area)
- Establishing incentives or ordinances, or a combination, that enable collaboration between landowners to encourage cooperation in development, design, and management strategies that reduce fragmentation and extend natural areas and ecosystem services.

7.2. Maintain and create habitat corridors through reforestation or restoration

Corridors that connect fragmented areas will help build resilience in ecological communities and will be essential to those landscapes acting as species migration corridors in response to climate change. Their presence will also help to minimize the effects of climate change on species whose habitat patches may be damaged or destroyed. In urban areas these corridors are both especially valuable and especially vulnerable (to development, degradation, or fragmentation) (Bryant 2006). Management strategies that protect existing corridors or create new ones through restoration or reclamation will be valuable in maintaining urban landscapes as regional migration corridors.

Examples of adaptation tactics are:

Urban natural areas

- Using urban tree canopy and other geospatial data to identify new and existing migration corridors
- Acquiring property for preserves or creating easements on private landholdings to create corridors between existing natural areas
- Managing natural areas that act as corridors to promote their maximum habitat value (e.g., by removing invasive species) and prioritizing management in those locations
- Creating artificial corridors (e.g., safe road crossings) at key dispersal or migration locations for wildlife (Beier and Noss 1998).

Developed urban sites

- Managing areas that could act as corridors between natural areas to mimic habitat and ecosystem structure of the natural habitat (e.g., by maintaining or promoting oak canopy cover in a residential development between two oak woodland natural areas while avoiding the creation of ecological traps in these areas (Battin 2004)
- Managing riparian corridors within otherwise highly developed landscapes to provide habitat value and ecosystem services (Groffman et al. 2003).

Strategy 8: Maintain and enhance genetic diversity

Reduced gene flow of remnant native populations and the prevalence of genetically identical cultivars in urban areas contribute to a reduction in genetic diversity of the urban forest. Urban natural areas are heavily fragmented, which can cause reduced gene flow and lead to a decline in genetic diversity (Young et al. 1993). Morphological uniformity is a priority in street and park trees. Most street and park trees are cultivars, or are grown from seeds that are sourced from a small number of parents to ensure that trees have predictable growth, survivorship, and tolerances. At the same time, morphological uniformity often comes at the expense of genetic diversity, and in changing conditions, a lack of genetic diversity may prove to be deleterious to long-term survivorship (Raupp et al. 2006). For example, if all of the maple trees in an area are a single cultivar, they will probably react to climate change in a nearly identical manner. Increasing genetic diversity in the urban forest will ensure that some individuals are better equipped to withstand climate-induced stressors.

Approaches:

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range

Although seeds from local sources may be the best adapted for an area currently, they may be maladapted to the changing climate in coming decades (Vitt et al. 2010). Alternatively, seeds that are native to areas with a climate similar to the projected climate of the target region may have higher survivorship than local seeds if other habitat factors (e.g., soils) are also suitable (Pedlar et al. 2012). In addition, the unique climate in an urban center may already necessitate a different set of genetic material than for more pristine natural areas. Trials can help ensure that seedlings from distant areas will thrive in a new environment before large-scale plantings are undertaken. Other risks associated with introducing seeds from distant sources include the potential for also introducing exotic pests and diseases, or the possibility that the introduced species may become invasive, hybridize with other local species, or cause outbreeding depression (Ricciardi and Simberloff 2009, Vitt et al. 2010). These risks are reduced, but not eliminated, when a species is moved within its native range (Pedlar et al. 2012)

Examples of adaptation tactics are:

All urban sites

- Using climate change projections to determine what region currently has a climate that is similar to the expected future climate in the target area and sourcing seeds from this area
- Creating a dialogue with nurseries and growers to ensure that seeds are being selected from healthy trees in areas that have a climate that is similar to the target area's expected climate
- Using mapping programs to track the origin of seed stocks and monitor their success to inform seed sourcing decisions from in the future
- Sourcing seeds from a variety of areas to increase overall genetic diversity
- Planting and producing individuals collected or propagated from a variety of sites (including drought- and flood-prone areas) because of uncertainty in future conditions.

8.2. Favor existing genotypes that are better adapted to future conditions

Urban trees are generally selected for their shape, height, pest and disease tolerance, and tolerance of harsh urban conditions. However, other factors such as tolerance of heat, drought, wind, or flooding may become more important under changing climate conditions. Some individuals in a diverse forest may already possess genotypes that make them more resistant to pests, drought, or other climate-related changes (Millar et al. 2007). Identifying genotypes that will be adapted to future conditions will be a complex endeavor, given the range of different stressors that may be intensified directly or indirectly due to climate change. Through time, these individuals could be identified through monitoring and research and used to propagate future generations.

Examples of adaptation tactics are:

All urban sites

- Collecting and planting seeds from individuals that have survived dieback events (such as pest outbreaks or drought) as these individuals may have resistant genotypes
- Collecting and planting seeds from individuals that have survived extreme weather events such as droughts or floods as they may be more tolerant of these stressors.

8.3. Use new genotypes that are better adapted to future threats and conditions

It may be easier to introduce new genetic diversity into urban forests compared to natural forests, because it is already routine practice to introduce cultivars of a given species. With care, the introduction of new cultivars can be used to create a more resilient urban forest. In many cases, cultivars for a given species have already been developed for several different climate zones. For example, the sugar maple cultivar 'Unity' was developed for hardiness in Manitoba (USDA zone 3), and 'Astis' was bred to thrive in the U.S. Southwest (zone 5). As the climate changes, cultivars that were developed for drier and warmer regions may be best suited for new locations. Using cultivars to increase genetic diversity may be suitable only for developed urban sites, however, because these individuals may not reproduce in natural areas or otherwise may not thrive in a natural ecosystem.

Examples of adaptation tactics are:

Developed urban sites

- Using cultivars of species that will be better suited for hotter and drier climates
- Working with growers to create new genotypes and cultivars of currently planted species that will be best adapted to climate changes
- Using a variety of cultivars to increase overall genetic diversity
- Planting disease-resistant cultivars that had been previously lost due to pests or disease in order to reestablish a form of this species on the landscape, such as disease-resistant elm or chestnut.

Strategy 9: Facilitate composition adjustments through species transitions

Urban areas already contain a broad mixture of species that come from outside of the area. Because these species evolved in different climates, they will probably have very different tolerances to future climate conditions. In the urban landscape, fostering species transitions is less a question of whether to assist migration of species from other geographies; this is already a common occurrence. Instead, it is more about deciding when and where to incorporate species into forests and plantings in different habitats and land uses. These species could be nonnative taxa or species that are regionally native, that is, those from the same region but not currently growing at that particular location. In addition to increasing the climatic resilience of the urban landscape, urban forests could also facilitate the migration of species that will be favored under future climate to new habitats at or beyond the edges of their current range (Woodall et al. 2010).

Approaches:

9.1. Favor or restore native species that are expected to be adapted to future conditions

Selecting native species already present in an urban area that are likely to do well under a range of future climate conditions can be a low-risk approach for transitioning to future climate conditions. Native species can provide important ecosystem services such as habitat for vertebrate and invertebrate species, and do not carry a risk of becoming invasive, spreading new diseases, or leading to genetic mixing. However, there may be a limited set of native species that will be able to withstand future climate conditions and also be adapted to harsh urban environments. Therefore, this approach will probably need to be balanced with other approaches to ensure sufficient biodiversity in an area.

Examples of adaptation tactics are:

Urban natural areas

- Planting native seedlings in restoration projects that are likely to do well based on climate model projections and information about climatic tolerances.

Developed urban sites

- Prioritizing native species that are near their northern range limit when promoting and developing native species for use in urban planting lists.

9.2. Establish or encourage new mixes of native species

Future conditions in urban areas are likely to become especially extreme, with higher peaks in temperature and moisture than might be seen in nonurban landscapes (McCarthy et al. 2010). However, considerable uncertainty exists in what future conditions will be, especially at the site level. Thus, encouraging new mixtures of native species and regionally, but not locally, native species in forest communities and plantings could help these systems adapt and maintain ecological function (Millar et al. 2007). This approach could also discourage invasion by exotic invasive species (Naeem et al. 2000). Managers may need to prioritize diversity (both in terms of species as well as functional groups and phylogenetic lineages) over historical species combinations to increase community resilience.

Examples of adaptation tactics are:

Urban natural areas

- Planting a mixture of locally and regionally native species during ecosystem restoration to allow for uncertainty in future conditions at the site level, and not necessarily planting just those species that are best adapted to current site conditions or that made up the historical community on the site
- Creating heterogeneous conditions in canopy structure, ground layer, and hydrology that will allow a variety of species to become established.

Developed urban sites

- Including a diverse mix of locally and regionally native species in plantings, especially in plantings that are near natural areas.

9.3. Select tree species to match current and future site conditions

Many trees in urban areas are individually selected for a particular site, allowing a high degree of flexibility. Species selection for a given site can also take likely future climate conditions into account. For example, flood-tolerant species may be selected for areas that fall into a moderate-risk flood zone because flooding in the area is projected to increase. Matching planted trees to a range of current and future conditions is likely to be more feasible than attempting to alter growing conditions to match a preferred tree species. Furthermore, selecting trees that are known to be well matched to growing conditions may increase the trees' ability to reach maturity, contribute to a healthy forest, and provide environmental benefits (Nowak et al. 2006).

Examples of adaptation tactics are:

Urban natural areas

- Planting dry-mesic species in mesic sites that are projected to become drier
- Planting heat-sensitive species on north slopes or in cold air drainages.

Developed urban sites

- Selecting species that can withstand poor site conditions near roads maintained with salt, sand, or other winter additives and that also can tolerate a range of other climate-related stressors
- Selecting trees that are hardier to extreme storm events and less likely to break up when pruned correctly, especially in wind-prone areas
- Planting tree species that are less sensitive to increased flooding and ponding in low-lying areas expected to get wetter.

9.4. Protect future-adapted seedlings and saplings

A wide variety of potentially damaging agents and practices are present in the urban environment, including many direct anthropogenic influences that are less of a concern in nonurban landscapes (Clark et al. 1997). Care should be taken to avoid damaging those species, communities, and ecosystems that are likely to be most well adapted to future climates during development of restoration and management projects.

Examples of adaptation tactics are:

Urban natural areas

- Protecting seedlings and saplings of desirable species during restoration and management operations by using barriers or fencing to discourage trampling.

Developed urban sites

- Avoiding damage to existing young trees of future-adapted species and cultivars during redevelopment projects.

9.5. Disfavor species that are distinctly maladapted

Urban areas are expected to experience especially rapid changes in climatic extremes, and some species at the edges of their natural ranges may more quickly become maladapted to these conditions (Walther et al. 2002). In addition, urban environments are already extreme in many senses and more species may eventually become poorly adapted there. For example, species whose range is projected to encompass an urban area may not be able to tolerate conditions in more-extreme urban microclimates.

Examples of adaptation tactics are:

Urban natural areas

- Using information from especially extreme urban sites or areas with similar climatic extremes and fluctuations to determine which native species are likely to decline
- Selectively removing or not replacing species that are not drought-, heat-, or flood-tolerant to promote establishment of more-tolerant native or near-native species.

Developed urban sites

- Selectively removing or not replacing species that are not drought-, heat-, or flood-tolerant
- Protecting healthy legacy trees that fail to regenerate, while deemphasizing their importance in the mix of species being planted or regenerated.

9.6. Manage for species or genotypes with wide moisture and temperature tolerances

Urban areas often experience even greater stress from heat, flooding, and drought than natural areas due to suboptimal growing conditions and high amounts of impervious cover. This additional stress, coupled with the uncertainty inherent in future climate projections, means that selecting for any particular future scenario may have some risk. A focus on species with large latitudinal ranges and wide tolerances may allow for better resilience (Millar et al. 2007).

Examples of adaptation tactics are:

Urban natural areas

- Planting seedlings of native species from a wide range of source locations (including non-local populations) when conducting restoration and reclamation treatments
- Using prescribed fire to favor species that have very broad latitudinal ranges and environmental tolerances.

Developed urban sites

- Planting a variety of both cultivars and wild genotypes for a given species
- Encouraging the planting of species that are adapted to wide tolerances rather than just specific current conditions (e.g., a species that is both drought- and flood-tolerant) in municipal planting lists.

9.7. Introduce species that are expected to be adapted to future conditions

Urban sites can act as locations for incorporation of regionally native species and could potentially help facilitate the movement of species within or outside of their current ranges (Woodall et al. 2010). Southern or drought-adapted genotypes and populations can also be incorporated into urban areas to help facilitate the adaptation of species and communities in the region to future climates (Millar et al. 2007). This idea is not new to urban forestry: Urban foresters have moved species across states, continents, and even oceans for centuries. However, the emphasis of this approach is to focus on those species that are most likely to align with future climate conditions. This approach can include relatively low-risk actions, such as moving a species to slightly north of its current range, but could also include riskier actions such as introducing a nonnative species from another continent. Careful consideration of these high-risk actions is warranted, especially before widespread implementation. Smaller trials may be helpful in assessing invasiveness and other issues.

Examples of adaptation tactics are:

Urban natural areas

- Incorporating regionally, but not locally, native species as well as nonnative species into reclamation projects in degraded habitats to assess their viability and aggressiveness
- Encouraging southern species that become established in natural areas.

Developed urban sites

- Increasing the representation of or incorporating new regionally native or likely future native species in urban planting projects, for example, Kentucky coffeetree or tuliptree in upper Midwestern cities
- Planting nonnative species from analogous climates.

9.8. Move at-risk species to locations that are expected to provide habitat

The climate may be changing more rapidly than some species can migrate, and the movement of species may be restricted by land use or other impediments between areas of suitable habitat (Davis and Shaw 2001, Iverson et al. 2004a). Fragmentation of habitat and physical barriers in urban areas may make this even more challenging, especially for rare or threatened species. Species-rescue assisted migration, focused on avoiding extinction by physically relocating climate-threatened species, may be an option to consider in some cases. This approach is best implemented with great caution, incorporating due consideration of the uncertainties inherent in climate change, the sparse record of previous examples, and continued uncertainties of forest response (Ricciardi and Simberloff 2009).

Examples of adaptation tactics are:

All urban sites

- Planting or seeding a rare or threatened plant species that is at risk for extinction to a newly suitable habitat outside its current range
- Assisting the migration of wildlife around barriers by trapping and releasing in newly suitable locations.

Strategy 10: Realign urban ecosystems after disturbance

Urban areas, in particular, may face dramatic impacts as a result of climate change-related alterations in disturbances, including pest outbreaks, floods, and storm events. As with natural ecosystems, some of the best opportunities for addressing disturbance-related impacts may occur immediately after the disturbance event; having a suite of preplanned options in place may facilitate an earlier and more flexible response. Urban areas faced with disasters are provided the opportunity to rebuild, and can use this opportunity to create an urban landscape that is better aligned with current and future climate conditions.

Approaches:

10.1. Promptly revegetate sites after disturbance

Changes in climate will probably lead to increases in large-scale disturbances such as floods and wind storms. These disturbances can lead to catastrophic losses of trees and other vegetation in some areas. Quickly reestablishing vegetation on disturbed sites will be necessary to maintain the climate mitigation services associated with urban forests and could help reduce the impacts of invasive species. In highly developed areas, replanting may be the only way to ensure the presence of species that provide the desired ecosystem services such as shade, aesthetics, or stormwater control. In natural areas, where a native seedbank may remain, replanting or managing natural regeneration may be beneficial to ensure the area has a species composition and structure that are aligned with management goals.

Examples of adaptation tactics are:

Urban natural areas

- Managing for natural regeneration of native species after disturbance through such practices as protecting seedlings and saplings from herbivory
- If possible, using the disturbance as an opportunity to eradicate or reduce the impact of invasive species
- Prioritizing planting of trees into recently disturbed areas
- Allowing nonnative species to remain as part of a novel mix of species, rather than eradicating these species.

Developed urban sites

- Planting new trees, with an emphasis on increasing diversity
- Spacing out planting over several years to create a diverse age and size class structure in the urban canopy.

10.2. Prioritize remediation of remaining trees following disturbance

In most cases, disturbances will not lead to complete loss of vegetation, but the remaining trees may have some degree of damage. After urgent severe hazards are dealt with, it is important to assess the damage to the remaining urban forest. This is the time to prioritize the level of importance for removal of severely damaged trees. Every attempt should be made to retain and restore amenity trees, especially legacy trees. The retention of these trees can help provide ecosystem services while new trees and other vegetation are becoming established.

Examples of adaptation tactics are:

Urban natural areas

- Retaining nonhazardous dead and damaged trees for wildlife habitat and other ecosystem services.

Developed urban sites

- Removing remaining severely damaged trees that were not immediately removed during emergency response
- Implementing appropriate tree crown restoration pruning strategies for less severely damaged trees
- If possible, standing fallen trees back up and using stakes or guy wires for support until the root system is structurally stable (usually newly planted trees or trees less than 4 inches in diameter).

10.3. Realign significantly disrupted ecosystems to meet expected future conditions

Many urban areas may experience such significant alterations from human- and climate-induced disturbance that it will become difficult to restore systems that reflect native ecosystems of the past. Management of these systems may be realigned to create necessary changes in species composition and structure to better adapt forests to current and anticipated environments, rather than historical pre-disturbance conditions (Millar et al. 2007, Spittlehouse and Stewart 2003). In more developed areas, this could mean designing “novel ecosystems” that incorporate both natural and engineered elements and contain entirely new species compositions (Hobbs et al. 2006). Developing clear plans that establish processes for realigning significantly altered ecosystems before undertaking these actions will allow for more thoughtful discussion and better coordination with other adaptation responses.

Examples of adaptation tactics are:

Urban natural areas

- Allowing community transition by planting future-adapted species within a site that is already declining or is expected to decline (e.g., converting a mesic maple forest to an oak savanna)
- Allowing nonnative species to remain as part of a novel mix of species, rather than eradicating these species.

Developed urban sites

- Designing “novel ecosystems” composed of a carefully selected mix of native and nonnative species that align with projected future climates.

CHAPTER 5. Adaptation Workbook

Climate change is becoming an increasingly important consideration in land management planning and decisionmaking at a variety of spatial scales. This chapter outlines a process to help natural resource managers incorporate climate change considerations into management planning and activities, while complementing existing processes and procedures for making decisions (Box 14). It also contains instructions for the Adaptation Workbook, which helps land managers work through this process step-by-step and identify actions that can help ecosystems adapt to climate change.

Incorporating Climate Change Considerations into Management

Land management agencies and organizations are under increasing pressure to integrate climate change considerations into planning and implementation activities. In recent years, a great deal of work has occurred to provide conceptual frameworks (e.g., Millar et al. 2007, Peterson et al. 2011), compile adaptation strategies (e.g., Heinz Center 2008, Heller and Zavaleta 2009, Ogden and Innes 2008), and provide tools to support management decisions (e.g., Cross et al. 2012, Morelli et al. 2012, Stein et al. 2014). At the same time, there remains a critical gap between the synthesis of scientific information on climate change vulnerability and adaptation and the actual integration of these ideas into management plans and practices (Carlton et al. 2014).

This chapter describes a flexible approach to address this issue and translate largely broad-scale and conceptual information into tangible actions that can be used by forest managers and other

Box 14

Using the Adaptation Workbook

The Adaptation Workbook can help natural resource managers:

- View climate change as an emerging management consideration that can be incorporated into many aspects of existing management planning and decisionmaking
- Integrate a wide variety of adaptation strategies and approaches into management decisions based upon existing management goals and objectives
- Discuss climate change-related topics with coworkers, team members, and other collaborators
- Document considerations and decisions regarding climate change and management.

The Adaptation Workbook does not:

- Make recommendations or set guidelines for management decisions or actions
- Establish a plan for implementation of the selected tactics and monitoring efforts. Rather, that step is reserved for managers to pursue after completing the workbook.

natural resource professionals to advance their on-the-ground work. It is designed to accommodate a diversity of management goals, ecosystems, ownership types, spatial scales (e.g., stand, large ownership), and levels of decisionmaking (e.g., planning, problem solving, implementation) (Janowiak et al. 2014b, Swanston and Janowiak 2012). Through this approach, managers begin with the current management goals and objectives for a particular forest management project (Fig. 12). Climate change is then incorporated as an additional "filter" through which to consider potential management responses and outcomes. Once adaptation actions are identified to help achieve management goals, monitoring is used to evaluate whether the goals and objectives were achieved, as well as to assess the role of the selected adaptation actions in meeting the desired outcome. This approach draws upon regionally specific information on anticipated climate change effects, such as vulnerability assessments, as well as the Adaptation Strategies and Approaches in Chapters 3 and 4 of this document.

One of the strengths of this approach is the flexibility that is built in to account for different future conditions. Given the need to make decisions despite incomplete information and to "learn by doing," adaptive management principles are well suited for incorporating climate change considerations into management (Millar et al. 2012, Stankey et al. 2005). Several aspects of adaptive management are evident in working through this approach, including explicit acknowledgment and consideration of uncertainty, iterative learning to improve understanding and reduce uncertainty, integration of monitoring, and a focus on continued improvement to achieve desired outcomes (Larson et al. 2013, Williams et al. 2007). In particular, the intentional use of monitoring to evaluate the effectiveness of adaptation actions helps to inform future management decisions. Further, because the individual steps mirror other processes used during management planning, ideas generated through the consideration of climate change can be easily incorporated into management plans, silvicultural prescriptions, or other plans.

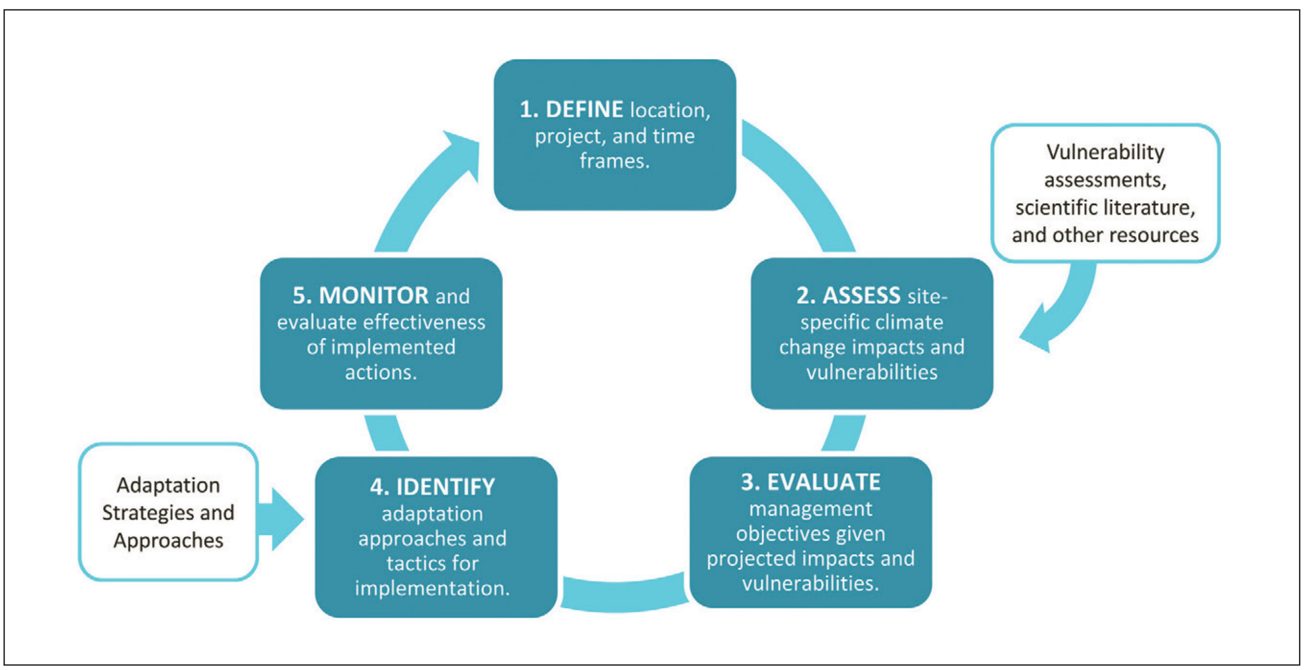


Figure 12.—An illustration of the adaptation process used to incorporate climate change as a management consideration and help ecosystems adapt to the anticipated effects of climate change. Additional resources provide information and tools that support the process.

Another strength of this approach is that hundreds of natural resource managers across diverse forest management and conservation projects have tested and applied it. A variety of public, private, nongovernmental, and tribal natural resource managers are using this approach to develop projects that implement a diversity of adaptation actions while also meeting manager-identified goals (Janowiak et al. 2014b). More than 200 adaptation demonstrations have been developed, ranging in size from stand-level silvicultural prescriptions to management plans covering thousands of acres. These demonstrations serve as examples of how this process has been applied in real-world natural resource management planning and projects. Examples of these projects are provided in Chapter 6 and at www.forestadaptation.org/demos.

About the Adaptation Workbook

The Adaptation Workbook is intended to help natural resource managers consider climate change in resource management activities. It builds upon the adaptation process described earlier in this chapter (Fig. 12), and provides additional details and items for consideration in each of the five steps. Rather than providing specific guidance or replacing other forms of management planning, the Adaptation Workbook draws upon the experience and expertise of natural resource professionals and complements existing management planning and decisionmaking systems.[1]

Because the Adaptation Workbook is designed to be flexible and used in a wide range of applications, it provides a general structure that can then be adjusted to include more or less information as desired. Three different versions of the Adaptation Workbook are available to lead managers through the same series of steps and considerations; managers can select the version that best meets their needs (Box 15).

[1] The Adaptation Workbook is designed to supplement and support existing decisionmaking processes in the U.S. Forest Service and other agencies or institutions, but does not in any way replace, supersede, or circumvent those processes.

For all versions of the Adaptation Workbook, natural resource managers are asked to draw upon information from a variety of resources, such as local and regional vulnerability assessments and the Adaptation Strategies and Approaches presented in Chapter 2 of this document. Because the understanding of the impacts of climate change is continually changing and growing, we recommend that users consult recent information and resources that are relevant to their particular location and management interests. Several resources are recommended where appropriate. We also encourage users to consult with scientists and others with expertise on climate change impacts to obtain relevant and up-to-date information to include in this process.

Getting Started

To get an overview of the process before you begin using the Adaptation Workbook, it is recommended that you first review the directions for all five steps. Select a version of the workbook that meets your needs (Box 15). Then collect any information, including relevant maps and management plans, which may be needed to provide additional information about your project area (Table 3). Tables have been provided in the workbook to show how information is arranged, and you can use electronic spreadsheets for capturing your notes while working on the short or complete versions of the workbook (Appendixes 4 and 5). The online version of the workbook is available at www.adaptationworkbook.org.

The Adaptation Workbook can be used by an individual or by a team of specialists, and this will influence how the process is completed. If you are working individually, it is likely that you will work your way through each of the steps more or less in sequence. If you are working as part of a team, it may be more efficient for one or two people to pull together much of the needed information to create initial drafts of Steps 1 and 2 (Table 3), which the larger group can then review and discuss.

Box 15

Other Adaptation Workbook Versions

The Adaptation Workbook outlines a broad, adaptive approach for integrating climate change into management while also prompting users to consider specific information and ideas that will help inform decisionmaking. Although the comprehensive version of the workbook featured in this chapter provides a starting point for those who are new to the process or prefer to view it all in one document, other versions of the workbook may be more appropriate for other applications (Table 2).

- The online version of the workbook (www.adaptationworkbook.org) follows from the workbook presented in this chapter, but includes additional capabilities for integrating regional climate change impacts from multiple vulnerability assessments.
- A short version of the workbook is included in Appendix 4 of this document. It leads users step-by-step through the "big questions" of the overarching adaptation process. Because of this condensed approach, it is more suitable for use by individuals who have previously used the comprehensive or online version of the workbook and for less complex projects.

Table 2.—Explanation of the different versions of the Adaptation Workbook

Version	Contains	Most suitable for users who are:
Comprehensive (worksheets follow p. 145 in Appendix 5)	A complete set of climate change considerations and detailed step-by-step instructions for using the adaptation process	First-time users of the workbook Less familiar with the information on projected climate change impacts Working in situations where the consideration of climate change in management needs to be documented
Short (worksheets follow p. 138 in Appendix 4)	A streamlined set of considerations that uses the overarching adaptation process	Familiar with the adaptation process or have used the comprehensive workbook before Familiar with projected climate change impacts Working in situations that do not need detailed documentation
Online (www.adaptationworkbook.org)	A comprehensive set of climate change considerations and detailed step-by-step instructions for using the adaptation process, as well as links to regionally relevant information and resources	Comfortable working with an online tool First-time or repeat users of the workbook Working on relatively small projects, such as a small property or single management unit

Table 3.—A list of resources and information that may be helpful in completing the Adaptation Workbook. If a team is going to complete the workbook, it is recommended that relevant information from this list is prepared and disseminated to team members before completing the workbook.

Workbook step	Materials needed	Potential sources for information
All steps	Adaptation workbook worksheets	URL for files
Step 1	Relevant maps of the location, such as: Aerial photos Ownership, project, stand boundaries	Geographic information systems (GIS) databases Mapping software, such as that available through Forest*A*Syst (www.forestasyst.org) or MyLandPlan (www.mylandplan.org)
Step 1	Management goals and objectives for the project area	Forest or land management plans Other planning documents
Step 1	Information on past and future management	Management records GIS databases
Steps 2 and 3	Information on regional projected climate change effects on ecosystems	Forest Ecosystem Vulnerability Assessments (Box 2 on p. 7) Regional vulnerability assessments (selected list available at www.adaptationworkbook.org) Other vulnerability and impact assessments (see Chapter 2 for more details on this type of information) Climate Change Resource Center (www.fs.usda.gov/ccrc)
Steps 2 and 3	Location-specific information that may help assess anticipated climate change impacts, such as soils, hydrology, habitat type, or past management influences (see Steps 1 and 2 for more details)	Forest or land management plans Local or regional ecosystem descriptions and assessments GIS databases or mapping programs Management records Local expertise
Step 4	A list of potential adaptation approaches that may be suitable for your forest ecosystem	Adaptation Strategies and Approaches (Chapters 3 and 4 of this document) Other lists of adaptation actions, such as the list at www.adaptationpartners.org/library.php Available literature on forest adaptation to climate change (see the Literature Cited section and Appendix 1 for some resources)
Step 5	Information about any forest inventory or monitoring that is taking place in (or near, if relevant) to the project area	Forest or land management plans Monitoring reports Other planning documents Regional forest monitoring programs

In general, it works well to organize information in the workbook by ecosystem types or management topics; these will generally be the same groupings as you would use for other management projects. Additionally, you may decide to further subdivide your project area into more precise ecosystem groupings or by management units or stands.

After you have organized your information, it may be most effective to move through the workbook by completing a single step for all parts of the project, and then moving on to the next step (as opposed to completing Steps 1 through 5 for a single ecosystem type and then moving on to the next type). This allows for better consideration of the interactions between the different ecosystem types at a larger geographic level, such as across an entire project or property. It also tends to be a faster, more efficient way to complete the Adaptation Workbook.

At times you might get ahead of your place in the workbook and have ideas for future steps; this can be a good thing. Although you will generally go through the workbook sequentially, you may find it helpful to jump ahead or circle back from time to time. If you find yourself jumping ahead, be sure to write your ideas down regardless of where in the process they fall, and then return to where you left off.

Step 1: DEFINE location, project, and time frames

Key Questions:

- Where are you working?
- What are your management goals and plans for this area?

About this Step

This step records fundamental information about the project area or property that will be used for the workbook process. Because it serves as a starting point for the subsequent steps, management goals and objectives should be as specific as possible. In many instances, this information will already be available as part of a management plan or other planning document. If you will be going through the workbook as part of a group, it may be most efficient for one or two people to compile information for this step before any group discussions.

Description of Workbook Items

Project Area or Property – Name the project area or property.

Location – Describe the geographic location of the area that you are using for this project.

Ecosystem Type or Management Topic – List the ecosystem types or management topics that are relevant to your project area. Because this information is tied to the management goals and objectives, as well as how actions are implemented, you may want to subdivide areas based upon management units, stands, or other features.

Note: Sometimes the current condition of an ecosystem is different from the desired future conditions, and management seeks to change the community over time. If the management goals or planned activities will include the conversion of the current ecosystem to a different type, clearly describe both the current and desired future type (and conditions, where appropriate).

Management Goals – List the management goals for the project area (Box 16). These may include the desired future characteristics of the location, such as forest conditions, habitat characteristics, anticipated products, or other ecological features or services.

Management Objectives – List any management objectives for the project area (Box 16). These will explain how management goals will be achieved. There may be multiple objectives for a single management goal.

Time Frames – List approximate time frames for implementing management actions and for achieving management goals and objectives. As a default, identify a point in both the short term (10 years or less) and the long term (30 or more years) that you can use to consider and visualize how things may change over time.

Box 16

Goals and Objectives

Management Goals

Management goals are broad, general statements, usually not quantifiable, that express a desired state or process to be achieved (Society of American Foresters 2008). These could include desired future ecosystem conditions, habitat characteristics, forest products, or other services. They are often not attainable in the short term, and they provide the context for more specific objectives (Table 4).

Management Objectives

Management objectives are concise statements of measurable planned results that correspond to preestablished management goals and help to achieve a desired outcome (Society of American Foresters 2008). These objectives commonly include information on resources to be used and form the basis for further planning to define the precise steps to be taken to achieve the identified goals (Table 4).

Table 4.—Examples of a management goal and a corresponding management objective

Management goal	Management objective
Enhance tree vigor and quality	Maintain annual growth of 1.5 cords per acre per year for the next 15 years
Restore Kirtland's warbler habitat	Increase acreage of early successional pine habitats by harvesting and replanting 20 acres every 10 years

Step 2: ASSESS site-specific climate change impacts and vulnerabilities

Key Questions:

- How might the area be uniquely affected by climate change and subsequent impacts?
- How might regional impacts be different in the project area?

About this Step

Climate change will have a wide variety of effects on the landscape, and not all places will respond similarly. For this reason, it is critical not only to think about the general (e.g., statewide or regional) anticipated effects of a changing climate on ecosystems, but also to consider how specific places on the landscape may be affected.

In this step, you will consider broad-scale scientific information about the expected effects of climate change in your region using vulnerability assessments or other published sources. After identifying these relatively general impacts, you will use your expertise and experience to evaluate how your specific project area or property may be vulnerable to climate change. Because there is a great deal of variability among different locations, your understanding of specific site conditions in that location will help you to identify the more relevant management responses in later steps.

Description of Workbook Items

Ecosystem Type or Management Topic – Insert the forest type(s) or management topic(s) that you identified in Step 1.

Regional Climate Change Impacts and Vulnerabilities – Begin by creating a list of relevant climate change impacts and vulnerabilities for the region that you are working in. You may also want to include the source of this information. Some of this information may be relevant to the entire project area or property, while other information may be specific to some of the ecosystem type(s) or management topics(s) that you identified in Step 1.

Many resources on climate change impacts and vulnerabilities are available, such as reports and peer-reviewed papers on climate change. Several regions have a vulnerability assessment that describes this information for an entire region, as well as by forest or community type (see Box 2 on p. 7 for a short list of available assessments). If you are trying to determine whether a vulnerability assessment meets your needs, Chapter 2 provides a starting point.

Climate Change Impacts and Vulnerabilities for the Project Area or Property – As you consider the general impacts and vulnerabilities (above), draw upon your experience and knowledge of this particular area to describe more specific ways that your project area or property may be affected by a changing climate (see Box 17 for a list of considerations). For example, a forest may have greater vulnerability to anticipated increases in the frequency and intensity of storm events because the trees on site are more susceptible to windthrow. Alternatively, an area may have less risk from late-summer moisture stress due to its topographic position and high water table.

Vulnerability Rating – Vulnerability is the susceptibility of a system to the adverse effects of climate change (Chapter 2). It is a function of its sensitivity to climatic changes, its exposure to those changes, and its ability to cope with climate change impacts with minimal disruption (Glick et al. 2011, Levina and Tirpak 2006) (Fig. 13). For example, an ecosystem subject to few potential impacts and having a high adaptive capacity would be determined to have low vulnerability.

- **High** – Potential climate change impacts are expected to exceed the ability of the ecosystem to cope with impacts. Ecosystems may undergo changes that will disrupt important ecosystem functions and key environmental benefits.

- **Moderate** – Potential climate change impacts are expected to alter ecosystems, but ecosystems will be able to cope with some impacts.
- **Low** – Ecosystems are expected to readily cope with potential climate change impacts. It is not anticipated that climate change will have substantial negative effects on important ecosystem functions and environmental benefits.

Box 17

Climate Change and Your Project Area or Property

Most of the available information on the potential effects of climate change has probably been developed for spatial scales that are larger than your project area. It is important to consider not only this broad-scale information, but also how your particular project area may be more or less vulnerable to these effects. Factors that may influence risk and vulnerability for a specific location include:

- Landscape pattern
- Location, such as topographic position or proximity to water features
- Soil characteristics
- Management history or current management plans
- Species or structural composition
- Presence of or susceptibility to pests, disease, or nonnative species that may become more problematic under future climate conditions.

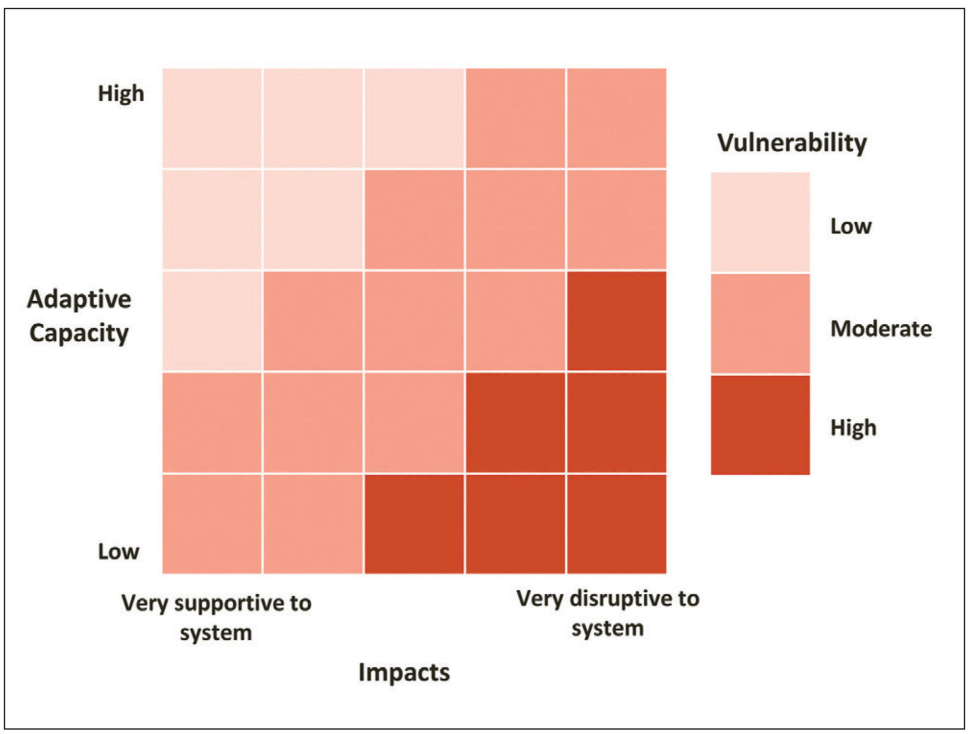


Figure 13.—Diagram that helps identify a vulnerability rating reflecting an ecosystem's sensitivity to climatic changes, its exposure to those changes, and its capacity to adapt to those changes while maintaining its character and function. Adapted from Swanston and Janowiak (2012).

Step 3: EVALUATE management objectives given projected impacts and vulnerabilities

Key Questions:

- What management challenges or opportunities might occur?
- Can current management meet management goals?
- Do goals need to change?

About this Step

In earlier steps, you defined management goals and objectives for your project area (Step 1) and considered climate change impacts and vulnerabilities for this area (Step 2). In this step, you will identify management challenges and opportunities associated with climate change. You will also evaluate the feasibility of meeting your management objectives under current management and consider whether they should be altered or refined to better account for anticipated climate change impacts.

Note: It is inevitable that discussion will jump ahead at times to identifying approaches or developing tactics that can help forests cope with the anticipated impacts; rather than lose these ideas or skip critical steps in the process, be sure to record any ideas that will be useful in later steps.

Description of Workbook Items

Ecosystem Type or Management Topic – Insert the forest type(s) or management topic(s) that you identified in Step 1.

Management Objectives – Insert the management objectives that you identified in Step 1.

Challenges to Meeting Management Objective with Climate Change – List ways in which climate change impacts and associated vulnerabilities may make it more difficult to achieve each management objective. For example, warmer temperatures and drier conditions may limit regeneration of a desired species and make it more challenging to maintain that species into the future. Focus on concerns related to ecological or environmental challenges; other considerations (e.g., financial, social) will be included later in this step.

Opportunities for Meeting Management Objective with Climate Change – List ways in which climate change impacts and associated vulnerabilities may make it easier to achieve each management objective or create new management opportunities. For example, increases in small- and medium-scale disturbance may help increase structural heterogeneity within a stand or landscape. Focus on concerns related to ecological or environmental challenges; other considerations (e.g., financial, social) will be included later in this step.

Feasibility of Meeting Management Objective under Current Management – Consider how the challenges and opportunities that you have identified may affect the feasibility of meeting your management objectives using *current* (business-as-usual) management strategies and actions. Feasibility can be determined for individual or multiple time frames (e.g., short-term versus long-term).

- **High** – Existing management options can be used to overcome the challenges for meeting management objectives under climate change. Opportunities are likely to outweigh challenges.
- **Moderate** – Some challenges to meeting management objectives under climate change have been identified, but these can probably be overcome by using existing management options. Additional resources or enhanced efforts may be necessary to counteract key challenges or promote new opportunities.
- **Low** – Existing management options may not be sufficient to overcome challenges to meeting management objectives under climate change. Additional resources or enhanced efforts will be necessary to counteract key challenges or promote new opportunities.

Other Considerations – List any social, financial, administrative, or other factors that are part of your decision to pursue your management objectives. You may also want to note reasons that you would continue pursuing a management objective with low feasibility, such as requirement by law, a high social value, or if an area with low feasibility has the highest likelihood of success when compared to other areas with low feasibility.

Slow Down to Consider…

Climate change may make some management goals and objectives more difficult to achieve in the future (Joyce et al. 2008, 2009; Millar et al. 2007), and there may be situations in which they need to be altered or refined to better account for anticipated climate change impacts. After completing Step 3, you should have a much better idea about whether your management objectives are feasible, given the current management options that are available to you. You have also identified social, economic, or other considerations that may affect your decision to pursue certain management objectives.

Are you going to continue with the management objectives you have identified?

If you have high feasibility of meeting your management objectives and these objectives are still sound given projected climate change impacts, you can proceed to Step 4 to explore adaptation actions.

If some or all of your management objectives have moderate or low feasibility, or if they no longer seem sensible under climate change (e.g., managing a species that very likely will experience a severe decline), you may reconsider your management objectives or your broader management goals. You can record any potential issues or changes in the "Other Considerations" section of Step 3 or return to Step 1 to alter your management goals and objectives. Use the information that you have gathered up to this point to create goals and objectives that are more likely to succeed, given projected impacts from climate change.

Step 4: IDENTIFY adaptation approaches and tactics for implementation

Key Question:

- What actions can enhance the ability of the ecosystem to adapt to anticipated changes and meet management goals?

About this Step

New or modified management practices may be needed to address the challenges to ecosystem management brought about by climate change. The Adaptation Workbook helps you identify and evaluate specific management actions that can help prepare for changing conditions given the challenges and opportunities that were identified in Step 3. In doing this you will generate a custom set of adaptation tactics—prescriptive actions specifically designed for your project area or property and your unique management objectives.

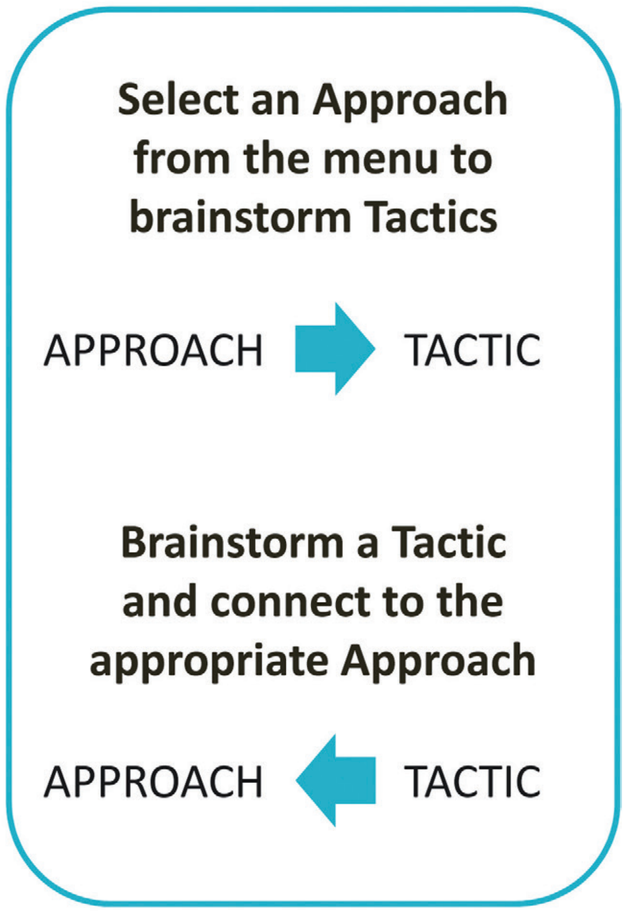
The step also helps you create a clear rationale for your suggested tactics by connecting them to broader adaptation ideas. Chapters 3 and 4 of this document contain menus of Adaptation Strategies and Approaches for forest management and conservation in natural and urban forests. As you brainstorm and evaluate ideas for adaptation tactics, you'll also link these specific ideas to the list of more general adaptation strategies and approaches. These links will provide important context and rationale to justify your adaptation tactics. If you need help brainstorming specific adaptation tactics, you can use the menu of strategies and approaches as a springboard to develop specific tactics that can help achieve your management objectives.

Description of Workbook Items

Ecosystem Type or Management Topic – Insert the ecosystem type(s) or management topic(s) that you identified in Step 1.

Adaptation Actions

- **Adaptation Approach** – Review the Adaptation Strategies and Approaches (Chapters 3 and 4) and select any approaches that you think may be applicable. Also include any additional approaches that you devise.
- **Tactics** – Describe specific actions that you can take in your project area to implement the adaptation approaches using your experience and expertise.



Because adaptation approaches provide context for specific tactics that will be implemented, we encourage you to include both; however, you may find it easier to list tactics first and then go back to identify the corresponding strategies and approaches.

Time Frames – List the approximate time frames in which the tactics would be implemented. The nature of the action can help determine an appropriate time frame. Some actions may occur in the short term (i.e., next 5 years), whereas others may not occur for several decades or will occur only in certain situations (such as after a large disturbance).

Benefits – For each tactic, list any benefits associated with using this tactic. For example, note if a tactic addresses your biggest challenge, addresses multiple challenges, or has a side benefit, such as improving overall ecosystem health.

Drawbacks and Barriers – For each tactic, list any drawbacks that may arise, such as negative ecosystem impacts, or any barriers to implementing the tactic, including legal, financial, infrastructural, social, or physical barriers.

Practicability of Tactic – An adaptation tactic is practicable if it is both effective (it will meet the desired intent) and feasible (it is capable of being implemented). Both of these characteristics increase the likelihood of success and are desirable in selected adaptation tactics. Consider the benefits, drawbacks, and barriers associated with each tactic in order to determine the practicability of meeting your management goals and objectives using that tactic (see Box 10 on p. 34). This is based on ecological and nonecological factors.

- **High** – The tactic is expected to be both effective and feasible. Benefits of the tactic clearly outweigh drawbacks and barriers.
- **Moderate** – There are drawbacks or barriers that could reduce the effectiveness or feasibility of the tactic. The use of other adaptation tactics or management actions may make it possible to overcome some drawbacks or barriers.
- **Low** – The tactic does not appear to be effective or feasible. The drawbacks and barriers are insurmountable or the benefits are too small relative to the required effort. The tactic may need adjustment to be made more effective or feasible.

Recommend Tactic? – Consider the time frame, benefits, drawbacks, barriers, and practicability for each tactic and select the tactics that you recommend for consideration in future management decisions. Tactics that overcome or avoid challenges, have high practicability, or have major benefits should be favored. For each tactic, determine whether you would recommend it for consideration in future management decisions:

- **Yes** – This tactic is likely to be helpful in overcoming management challenges from climate change and meeting management objectives, and it should be considered in future management decisions. If needed, note any barriers that must be overcome to use this tactic.
- **No** – This tactic is not helpful or cannot be used in overcoming management challenges or meeting management objectives, and it is not recommended for current consideration in future management activities.

As you identify recommended tactics, consider how they work together as a set of actions. The goal is to identify a set of actions that are complementary and help to overcome the barriers identified in the previous step in order to achieve your management goals and objectives.

Step 5: MONITOR and evaluate effectiveness of implemented actions

Key Questions:

- How do you know if the selected actions were effective?
- What can you learn from these actions to inform future management?

About this Step

Monitoring is critical for understanding what changes are occurring because of climate change as well as whether selected actions were effective in meeting management goals and adapting forests to future conditions. This step helps to identify metrics that will be used *to monitor whether management goals are achieved in the future and to determine whether the recommended management tactics were effective*. The outcome of this step is a realistic and feasible monitoring scheme that can be used to help determine whether management should be altered in the future to account for new information and observations.

There are several types of monitoring, and many efforts are already underway to monitor some indicators in the region. Most of these efforts are not designed to specifically monitor climate change, but they can still be useful in the context of climate change. Drawing upon and contributing to existing monitoring efforts when possible will help to detect changes that may not be detectable at smaller spatial scales and also may require fewer resources to implement. Consider what existing monitoring efforts are available and if they need to be modified to better monitor the results of your adaptation actions. Also consider what new monitoring items may be needed to evaluate whether you have met your management goals.

Description of Workbook Items

Ecosystem Type or Management Topic – Insert the ecosystem type(s) or management topic(s) that you identified in Step 1.

Adaptation Monitoring Variable – Identify monitoring items that will be used to evaluate whether you have achieved your management objectives and goals, or whether you have achieved a milestone that indicates progress toward your goal. When possible, select monitoring items that will also help you to understand whether the adaptation tactics recommended in the previous step were effective in working toward your management goals under climate change.

Criteria for Evaluation – Identify a value or threshold that is meaningful for this monitoring item. For example, you may have a goal of 70-percent seedling survival after 3 years if your project will include tree planting.

Monitoring Implementation – Describe how and when this information will be gathered. For example, you may monitor seedling survival every summer for 5 years after planting. It can be helpful and save resources to take advantage of existing monitoring efforts when possible.

Next Steps

Congratulations on completing the Adaptation Workbook! Now that you have considered how you can help your project area to adapt to the anticipated effects of climate change, you can work to integrate the information from the workbook, especially Steps 4 and 5, into existing management plans and decisionmaking processes. As you work toward this integration, it is important to keep in mind that the tactics you developed by completing the workbook have been recommended for further consideration (Step 4). Taking this step does not necessarily mean, however, that the tactics must be implemented or that the recommendations must supersede other considerations. The workbook was designed to lead you through a process for considering climate change, and it is up to you and your organization to determine the ways in which you will use the information and ideas you have developed.

Finally, the workbook is designed as part of an adaptive management process, which by definition needs to be able to incorporate new information as it becomes available. When developing a plan to implement your adaptation tactics and then monitor the results, also make plans to revisit this workbook as often as necessary to evaluate whether any changes are needed. Consult with experts whenever possible to gather new information and further refine your management decisions. As new information becomes available through scientific research, monitoring activities, or other avenues, use that information to consider how it may change your expectations about future conditions and whether it is appropriate to adjust your management or monitoring to better help the systems adapt to a changing climate.

CHAPTER 6. Adaptation Demonstrations

One of the unique aspects of the Climate Change Response Framework is that its comprehensive approach not only delivers high-quality information and tools, but also moves beyond general discussions of climate change to actual planning and implementation of adaptation in real-world management projects (Chapter 1). Climate-informed management actions identified and selected through the Adaptation Workbook (Chapter 5) are carried out in adaptation demonstration projects. Adaptation demonstrations serve as real-world examples of the integration of climate change information into natural resource management (Janowiak et al. 2014b).

More than 185 adaptation demonstrations have been developed in collaboration with a variety of public, private, nongovernmental, and tribal land managers to illustrate a diverse array of adaptation tactics (Fig. 14). These "case studies" reflect a variety of forest ownerships, management objectives, spatial scales, and complexity. In most of the adaptation demonstrations developed thus far, an individual or small group of landowners and land managers uses the adaptation workbook in a facilitated discussion or training session, which is led by a specialist with expertise in both climate change and forest management. This chapter summarizes five demonstration projects in order to show different applications of climate change adaptation in forest management. Additional summaries of adaptation demonstrations are available online at www.forestadaptation.org/demos.

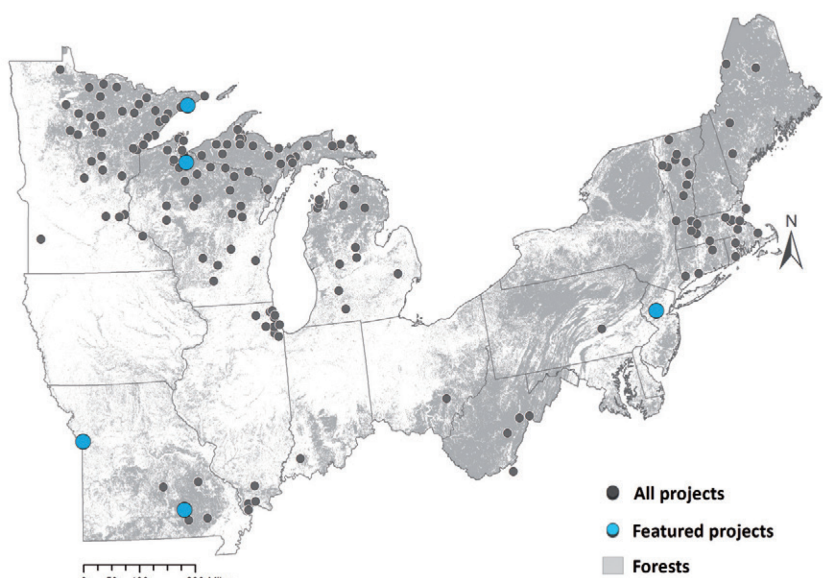


Figure 14.—Location of adaptation demonstrations developed through the Climate Change Response Framework as of the time of publication. Demonstrations featured in this chapter are identified with blue markers.

Caroline Lake Property

Project Area and Management Goals

The Nature Conservancy (TNC) owns and manages more than 1,000 acres of forest on the Caroline Lake Property (Fig. 15) in northern Wisconsin. The property was acquired from industrial ownership in 1997, and has since been maintained as a working forest to demonstrate sustainable forestry practices. Natural resource professionals from TNC and the Wisconsin Department of Natural Resources used the Adaptation Workbook with facilitation to consider climate change effects on the property as part of updating the property's forest management plan. A consulting forester worked with TNC staff to translate the proposed adaptation actions into stand-level recommendations for the new plan.

The Caroline Lake Property has been actively managed since 1997 with the intent of restoring characteristics associated with pre-European settlement forests. Much of the property contains upland northern hardwood forest, with numerous areas of lowland hardwood and conifer forest. Before considering the potential effects of climate change on the property, TNC management generally focused on:

- Encouraging mid- to late-successional forest characteristics
- Emulating natural disturbance dynamics
- Increasing underrepresented species
- Increasing age diversity
- Protecting water quality along headwater tributaries.

Figure 15.—A wetland at the south end of Caroline Lake in northern Wisconsin. Photo by Maria Janowiak, U.S. Forest Service.

Climate Change and the Caroline Lake Property

Climate Change Impacts

A vulnerability assessment for forest ecosystems in northern Wisconsin (Swanston et al. 2011) was used to identify potential climate change effects across the region. The managers combined this broad-scale information with their knowledge of the local landscape to identify attributes of the property that they believed would increase or decrease risks from climate change (Fig. 16). For example, many common tree species are projected to have reduced habitat suitability or productivity by the end of the century across northern Wisconsin (Janowiak et al. 2014a, 2014b; Swanston et al. 2011). In particular, black spruce, balsam fir, quaking aspen, and other boreal species are at the southern extent of their range in the region, and these species are projected to decline substantially over the next century under multiple climate scenarios. Other important species, such as sugar maple, eastern hemlock, yellow birch, and eastern white pine, are also projected to decrease due to climate change; however, the projected decreases are less than for boreal species and generally only under climate scenarios that project greater levels of climate warming. The high abundance of boreal and northern tree species on the Caroline Lake property puts the forest at risk from potential changes in composition. At the same time, the property has a notably high diversity of

Figure 16.—Forestry professionals discussing the adaptation demonstration at Caroline Lake. Photo by Maria Janowiak, U.S. Forest Service.

tree species compared to other tracts in the vicinity, which may reduce certain risks if one or a few tree species undergo especially large declines.

A number of other potential effects on the property from climate change were also considered. These included direct effects on forests from warmer temperatures, altered precipitation, and extreme weather events, as well as indirect impacts related to interactions with forest pests and diseases and other stressors (Janowiak et al. 2014a, Swanston et al. 2011). Projected changes in precipitation and associated hydrology were identified as having the potential to greatly affect forests, but these projections were also the most uncertain. Projections of summer precipitation are highly variable for the region, but the combination of earlier spring snow melts and warmer temperatures without a compensatory increase in summer precipitation generally suggests drier summer conditions and altered hydrology. Lowland conifer forests, which contain a disproportionate share of tree species that are expected to decline due to climate change, may be at particular risk if hydrology is disrupted.

Challenges and Opportunities for Management

In this step, managers explored the challenges and opportunities in meeting the property- and stand-level management goals and objectives under changing conditions. Many of the challenges were based upon the vulnerabilities identified in the previous step, such as the challenge of promoting eastern hemlock and yellow birch in the upland hardwoods stands when some model results suggest that these species are at increased risk of declining by the end of the century.

Some of the expected climate change impacts were perceived as potential opportunities. The species diversity in these stands provided many opportunities to maintain a sufficiently healthy forest and work toward goals related to increasing underrepresented species and increasing characteristics associated with older forests. Even increased frequency of disturbance from extreme weather events was viewed as a potential benefit (as long as the extent was not too great) because of the interest in incorporating natural disturbance patterns into management and increasing structural diversity. Although the managers did not feel that the management trajectory needed to change dramatically as a result of considering climate change, they recognized that it could become more challenging to reach some of the management goals for tree species composition, and that considering a broader suite of tree species could increase the likelihood of achieving other management goals.

Adapting to Climate Change

Approaches and Actions for Adaptation

Within this context, a number of potential adaptation actions were identified with the overarching intent to maintain the resilience of the forest to changing conditions (Table 5). In the northern hardwood forest, actions to maintain and enhance tree species diversity were prescribed to reduce the risk from climate change-related declines in the dominant species. This included the use of group selection and shelterwood harvests to enhance natural regeneration of mid-tolerant species. Several of these species, including northern red oak and black cherry, were present on the property in relatively low numbers and are projected to fare better under climate change compared to other species on the site. Eastern white pine was also identified as a desirable species. Although it is projected to decrease under some climate scenarios, the species is at a lower risk of decline than other native conifer species.

The managers generally viewed the proposed actions as slight adjustments to, rather than a significant departure from, the current management trajectory. Additionally, several "contingency plans" were discussed for responding to disturbances or other unforeseen events. For example, lowland hardwood forests were identified as at risk from altered hydrologic regimes and reduced late growing season soil moisture from climate change, introduction of the emerald ash borer, or a combination of these threats. Although no active management is currently planned in these stands, swamp white oak and bur oak were identified as two potential species that could be planted in lowland hardwood forests to maintain forest cover if intervention were deemed necessary. These species are not currently present on the property but can be found at the northern extent of their range in localized areas in northern Wisconsin, which would represent a small degree of assisted migration.

Monitoring

Managers from TNC and the consultancy responsible for the property management identified forest inventory data as an integral component of monitoring the effectiveness of adaptation actions over time. Permanent forest inventory plot locations were established in randomized locations across the property, and a comprehensive inventory was performed to document stand characteristics and ecological attributes. The robust inventory provided a useful baseline for prescribing management activities for adaptation. For example, data on tree species abundance were used to calculate tree species richness and diversity evenness and provided an indication of the relative risk associated with the loss of different tree species. Additionally, the presence of advance regeneration of northern red oak and black cherry (tree species that may be better adapted to future conditions) was evident in the inventory data. In the future, inventories repeated at approximately 10-year intervals will be used to evaluate whether the selected management activities increase the abundance of these species in the understory and eventually the overstory.

More Information

A forest management plan for the Caroline Lake Property integrates the ideas that managers generated while using the Adaptation Workbook. More information on this adaptation demonstration is available at www.forestadaptation.org/CarolineLake.

Table 5.—Selected proposed adaptation actions identified for the Caroline Lake Property in northern Wisconsin. The current management activities reflect the 2005 forest management plan and did not take the effects of climate change into account. The proposed adaptation actions were identified as part of the Adaptation Workbook process and will be integrated into a new, updated forest management plan.

Management area/topic	Adaptation approach	Proposed adaptation tactics
Northern hardwoods	Promote diverse age classes Maintain and restore diversity of native tree species Retain biological legacies	Use single-tree selection with additional use of targeted gaps and seed trees to maintain or enhance species diversity (e.g., mid-tolerant species) and age class diversity
	Favor or restore native species that are expected to be better adapted to future conditions	Use large group selection or shelterwood harvests to increase northern red oak component in areas where natural regeneration is present
	Prioritize and protect existing populations on unique sites Maintain and restore diversity of native tree species	Where opportunities exist, promote eastern white pine, black cherry, yellow birch, and other desirable species that have a lower risk of declining as a result of climate change Look for opportunities to reserve high-quality pockets of eastern hemlock on less vulnerable sites to serve as refugia for that species
Lowland conifer	Maintain or restore soil quality and nutrient cycling Maintain or restore hydrology	Maintain as no harvest reserve area Increase monitoring to detect hydrological changes in peatland systems; revisit planned management if changes are observed
Lowland hardwoods	Maintain or restore soil quality and nutrient cycling Maintain or restore hydrology Maintain or restore riparian areas	Maintain as no harvest reserve area
	Establish or encourage new mixes of native species Identify and move species to sites that are likely to provide future habitat	Monitor stocking and natural regeneration of desired species; if inadequate, consider experimental plantings of swamp white oak or bur oak as species that are not currently present in the area but may do well in the future
Shoreline buffer	Maintain or restore riparian areas Maintain and restore diversity of native tree species	Where opportunities exist, promote eastern white pine or other species to provide long-lived conifer component and shading along lake shorelines
Upland conifer	Maintain and restore diversity of native tree species Favor or restore native species that are expected to be better adapted to future conditions Manage for species and genotypes with wide moisture and temperature tolerances	Promote long-lived conifers, with additional emphasis on species that are at lower risk of decline under climate change, such as eastern white pine

L-A-D Foundation's Pioneer Forest and the Ozark National Scenic Riverways: Jerktail Mountain

At 140,000 acres, the L-A-D Foundation's Pioneer Forest is Missouri's largest private land ownership. Since the early 1950s, this forest has employed a conservative, uneven-aged management method known as single-tree selection harvesting. Decades-long application of this successful method on the Pioneer Forest indicates a truly sustainable forest management practice. Recognizing the importance of fire in managing glade ecosystems and shortleaf pine woodlands, foresters have developed fire prescriptions to reduce woody species encroachment, restore and maintain the targeted ecosystem, and enhance adaptive capacity to better cope with a range of future climates.

Ozark National Scenic Riverways was established as a unit of the National Park System by the U.S. Congress in 1964 to conserve and interpret the scenic, natural, scientific, ecological, and historic values and resources within the National Riverways, and to provide for public outdoor recreational use and enjoyment of those resources. The National Riverways includes portions of the Current and Jacks Fork Rivers, providing 134 miles of clear, free-flowing, spring-fed waterways. The overarching goal of the fire management program in the Riverways is to restore and maintain fire-dependent natural communities such as glades and woodlands.

Project Area and Management Goals

This project is located on a 1,836-acre tract within the Current River Hills subsection of the Missouri Ozark Highlands in south-central Missouri about 9 miles northeast of Eminence. The rugged terrain of the Current River Hills features extensive forest and woodlands with high ridges dominated by shortleaf pine and oak with scattered igneous and dolomite glades. The L-A-D Foundation and National Park Service each own portions of the Jerktail Mountain management area, and jointly manage and monitor the area. This project is supported in part by the Wildlife Conservation Society's Climate Adaptation Fund.

The overall goal of the project is to improve natural community health and resilience while also providing timber products. Two community types are found in the area: igneous and dolomite glades, and woodlands dominated by oak and shortleaf pine. The goal was to restore these ecosystems to natural conditions more in character with pre-European settlement conditions.

Specific objectives included:

- Restoring fire on the landscape by initiating a prescribed burn regime
- Removing encroaching eastern redcedar and nonnative invasive species
- Reducing the impacts of overuse
- Decreasing stand density to align better with local site conditions.

Climate Change and Jerktail Mountain

Climate Change Impacts

According to a recently completed vulnerability assessment for the Central Hardwoods region (Brandt et al. 2014), several climate change impacts are expected in the Missouri Ozarks region by the end of the century, including:

- Mean annual temperature increases from 2 to 7 °F (1.1 to 3.9 °C)
- Increased precipitation in winter and spring and potential declines in summer
- Increased frequency and severity of wildfire.

These climatic changes will affect local ecosystems in the Jerktail Mountain management area. Glades are primarily dominated by nonwoody species. Although future distribution of these nonwoody species has not been modeled, many are adapted to the hot, dry conditions that are expected to become more common. Nevertheless, a number of modeling studies in other areas have shown that some species with very narrow geographic distributions, like many glade-associated species, are more at risk to climate change. Post oak is typically found in glade systems, and habitat suitability for this species is likely to increase. Eastern redcedar encroachment

(Fig. 17) is the main issue negatively affecting herbaceous species on glades at this site, and that species is likely to expand in the future due to other factors besides climate change.

In the woodland, shortleaf pine and post oak are projected to benefit from a warmer climate. Shortleaf pine, however, is less prevalent in this site than in some nearby areas and will regenerate only on bare mineral soil in an open area. In addition, southern pine beetle could be a potential future risk for shortleaf pine, although risks are relatively low due to the low density of pine at the site. Other species common in the site, like black, chinkapin, red, and scarlet oak, are projected to be negatively affected by drier summers (Brandt et al. 2014). White oak is also common, and models suggest it may persist in the area at least over the next several decades. Woodlands are adapted to frequent, low-intensity fires, but could be negatively affected if fires become too severe.

Challenges and Opportunities for Management

Managers identified potential management challenges on both the glade and woodland sites. The increased likelihood of rain during the winter could make it harder to conduct prescribed burns in glades compared to the woodlands because glades can absorb water like a sponge in the spring. This could make it difficult to control or reduce eastern redcedar with fire alone, and mechanical treatment for eastern redcedar might be needed.

Shifts in precipitation could also alter the prescribed burn window, which might require the timing to be adjusted. Burn crews must be planned for months in advance, so it is hard to make last-minute changes to the timing of prescribed burns. It could also become more challenging to thin timber if conditions become too wet during some seasons, as there is an increased risk of damage to shallow roots and soil quality when operations are conducted on wet soils. Despite these challenges, the managers at Jerktail Mountain expressed confidence in their flexibility to make adjustments in their management as conditions change, especially with timber harvest.

Figure 17.—Encroachment of eastern redcedar on a glade ecosystem on Jerktail Mountain in south-central Missouri. Photo by Leslie Brandt, U.S. Forest Service.

Adapting to Climate Change

Approaches and Actions for Adaptation

Staff from the L-A-D Foundation and Ozark National Scenic Riverways used the Adaptation Workbook to identify actions to enhance the adaptive capacity of pine woodland ecosystems (Table 6). Adaptation tactics identified were closely in line with current management, but added an increased emphasis on restoring fire.

Monitoring

Monitoring for the two sites will be focused on assessing the effectiveness of achieving management goals. Restoration of the understory flora will be evaluated by monitoring herbaceous species richness and cover in plots both pretreatment and post-treatment. To assess the effectiveness of the treatments at reducing stand density (Fig. 18), the density of pole-sized trees will be monitored pretreatment and post-treatment and photo monitoring will be used for visual changes in structure and composition. Basal area, species composition, and growth of woody species will be monitored to assess how well the treatments favored future-adapted species. Shortleaf pine regeneration will also be monitored.

Table 6.—Selected proposed adaptation actions identified for the Jerktail Mountain adaptation demonstration in south-central Missouri

Management area/topic	Adaptation approach	Proposed adaptation tactics
Both sites	Restore fire to fire-adapted systems	Variable-intensity prescribed fire every 3 to 4 years initially, then shifting to every 5 years
	Maintain or restore soil quality and nutrient cycling	
Glade	Favor and restore native species that are expected to be better adapted to future conditions	Mechanical reduction of eastern redcedar to increase light penetration to the ground and reduce competition
	Prioritize and protect existing populations on unique sites	
	Prioritize and protect sensitive or at-risk species or communities	
Woodland	Maintain or improve the ability of forests to resist pests and pathogens Allow for areas of natural regeneration after disturbance Retain biological legacies	Selective thinning focused on removing scarlet oak and other species not favored under future climate conditions
	Maintain and restore diversity of native tree species	
	Disfavor species that are distinctly maladapted	
	Favor and restore native species that are expected to be better adapted to future conditions	

Figure 18.—Thinned woodland stand on Jerktail Mountain, Missouri. Photo by Leslie Brandt, U.S. Forest Service.

More Information

Implementation of this project began in 2014. More information on this adaptation demonstration is available at www.forestadaptation.org/Jerktail_Mountain.

Middle Blue River Watershed

Project Area and Management Goals

The Middle Blue River watershed (Fig. 19) is located in Kansas City, Missouri, and covers an area of 13,500 acres. It is one of 11 locations in the national Urban Waters Federal Partnership. The Kansas City Missouri Partnership has formed around four existing projects that have commonalities in their visions, planning elements, partners, and geographies in the Middle Blue River reach. This location is also at the confluence with Brush Creek, one of the Blue River's most visible and degraded tributaries. The watershed includes a mix of developed urban areas and upland and bottomland natural areas.

The Middle Blue River watershed has suffered from frequent and serious flooding, degraded water quality, habitat loss from channelization, and economic disinvestment and blight. However, the area is rich with potential for sustainable redevelopment and restoration. Municipal Farms, a largely abandoned site comprising multiple brownfields, has deep historical and cultural significance to the city and its residents. It also has extensive native wetland and upland areas, and a geographical nexus with the Blue River and Brush Creek confluence through the native stream Round Creek (Fig. 20). The former farm can be redeveloped to be a hub of connectivity to riparian greenways, conservation opportunity areas, and restoration sites that are being developed through the partnership project. This will address what local residents have identified as needs: connectivity, livable neighborhoods, recreation, river access, economic development, sustainable jobs, and access to fresh food.

Key management goals in the Middle Blue River watershed include:

- Conserving the health and sustainability of forests, savannas, glades, and other natural areas in the watershed
- Establishing and maintaining the ecosystem services of natural and urban ecosystems in the area, including minimizing stormwater runoff, improving water quality, improving air quality, and reducing urban heat island effects
- Maintaining and establishing high-quality wildlife habitat
- Improving the health and sustainability of residential and street trees in the watershed.

Figure 19.—Rocky Point Glade, Middle Blue River watershed, Kansas City, Missouri. Photo by Wendy Sangster, Missouri Department of Conservation, used with permission.

Figure 20.—Vegetation along the Blue River, Missouri. Photo by Wendy Sangster, Missouri Department of Conservation, used with permission.

Climate Change and the Middle Blue River

Climate Change Impacts

At the time of using the workbook, no climate change vulnerability assessment was available for the Kansas City area. Instead, managers of the Middle Blue River watershed relied on regional technical input reports from the National Climate Assessment (Melillo et al. 2014), tree species habitat suitability modeling results from the Climate Change Tree Atlas (Landscape Change Research Group 2014), and other relevant primary and secondary literature. Regional downscaled climate projections (Brandt et al. 2014) were also used.

One key climate change impact that managers identified as having the potential to affect the area is an expected increase in heavy precipitation events, which could increase runoff and the risk of severe flooding. Along with changes in precipitation and hydrology, temperatures in the area are projected to increase several degrees by the end of the century. Temperatures in some places in the watershed could be even more severe due to local urban heat island effects. The managers also discussed how changes in temperature and precipitation could lead to increased stresses on both native and cultivated species and increase habitat suitability for many weedy and invasive species.

Challenges and Opportunities for Management

Based on the projected impacts to the area, managers of the Middle Blue River watershed identified numerous potential challenges and opportunities in meeting their management objectives. Examples of climate change-related challenges for the management of the watershed are as follows:

- Tree species diversity may decrease as many trees become stressed from increased flooding, extreme heat, and reduced habitat suitability.
- It could become harder to manage invasive species due to a longer growing season and an increased range of southern invasive species.
- Extreme weather could inhibit recruitment and establishment of native species.
- In upland sites, there could be difficulty matching appropriate weather and time for prescribed burning.
- It could become challenging to find suitable species for planting in boulevards and yards that are able to withstand a suite of weather extremes.
- Climate-related stressors could increase the susceptibility of trees to pests and pathogens in both natural and developed areas.

Climate change-related opportunities for the management of the watershed include the following:

- Some native species could benefit from the projected changes in climate.
- Some invasive species might be negatively affected by extreme rain events and heat.
- A longer growing season could increase establishment of new tree species and cultivars in boulevard and residential plantings.
- A longer growing season could provide a longer window of opportunity for prescribed burns.
- Increases in temperature could increase public desire for shade trees to help mitigate heat island effects.
- New species that require less maintenance could be planted on developed sites.

Adapting to Climate Change

Approaches and Actions for Adaptation

Several adaptation approaches were identified across the watershed that differed by landscape position and land use (Table 7). Adaptation actions for bottomland natural areas centered on restoring hydrology to increase resilience to more-extreme runoff and rainfall. Upland area adaptation actions focused on restoring native ecosystems and favoring native species that are more likely to withstand projected changes in climate. In developed urban areas, adaptation actions focused on replacing declining urban trees with a new, more diverse mix of species that is better suited to future climate conditions.

Table 7.—Selected proposed adaptation actions identified for the Middle Blue River watershed adaptation demonstration in Kansas City, Missouri

Management area/topic	Adaptation approach	Proposed adaptation tactics
Riparian and bottomland areas	Maintain or restore hydrology	Create an incentive program that encourages residents and businesses to implement infiltration practices Adopt ordinances that require development plans to mimic predevelopment hydrology
	Prevent the introduction and establishment of invasive plant species and remove existing invasive species	Expand funding to remove bush honeysuckles and other invasive species through volunteer workdays and contracted removal Map honeysuckle by using aerial photography
Upland areas	Prioritize and maintain unique sites	Continue management of Blue River Glade as a natural area
	Favor or restore native species that are expected to be adapted to future conditions	Plant areas where natural regeneration is less likely Use species predicted to respond well to risks such as climate change and potential insect and disease problems
	Restore fire in fire-adapted ecosystems	Conduct prescribed burns using appropriate timing and frequency
Developed and urban areas	Disfavor species that are distinctly maladapted	Develop a replacement plan for declining and at-risk tree species
	Establish or encourage new mixes of native species that increase species diversity. Discourage species predicted to be maladapted to future risks	Develop recommendations for urban trees that include new species and discourage maladapted species

Adaptation actions identified were in line with conservation goals already identified by the partnership. However, managers felt that climate change places an additional urgency on restoring the system's hydrology and native species diversity while also identifying new species that may be better suited to future climates.

Monitoring

Managers of the Middle Blue River watershed identified a number of potential monitoring metrics to evaluate the effectiveness of their adaptation strategies. For example, in riparian areas, the number of acres of honeysuckles removed or replanted with desirable species would be measured. Across the watershed, changes in canopy cover in both developed and natural areas could be measured. In addition, as new trees are planted in developed areas, both the number and species diversity of trees could be monitored over time.

More Information

At this time partners have applied for several grants to support restoration efforts in the Middle Blue River watershed. These grants pertain to different geographic areas and address various issues. If these efforts are funded, the forest management adaptation plan created using the Adaptation Workbook will inform the scope of work that will be performed. More information on this adaptation demonstration is available at www.forestadaptation.org/MiddleBlueRiver.

Hudson Farm Club, Inc.

Organized in the late 1970s, Gracie & Harrigan Consulting Foresters, Inc. uses science-based forest management to serve more than 750 woodland owners, including families, major corporations, and nonprofit organizations. Together, they own more than 34,000 acres of woodland which benefit from sustainable forestry. Responding to climate change- and climate-related disturbances is an important part of sustainable forest management. Gracie & Harrigan Consulting Foresters, Inc. demonstrated how to incorporate climate change into private forest management through the project described below.

Project Area and Management Goals

This project covers about 3,000 acres of privately owned forest land in northern New Jersey. Most of the property is forested upland characterized by mid-successional, closed-canopy upland oak and northern hardwood forest. Due to a combination of past management, fire suppression, and natural succession, this forest type is beginning to shift from oak/hickory to northern hardwood forest. The management goals included:

- Improving the overall quality, health, and vigor of the forest
- Restoring early successional habitat for the state-endangered golden-winged warbler and other species in this niche
- Increasing species and structural diversity
- Retaining hard mast sources on the landscape.

Early management actions included a modified seed tree harvest that retained 10 to 15 songbird perch trees per acre preceded by removal of invasive plants. After 2 years, the high-quality seed bed provided a source for native plants, and there was aggressive stump-sprouting. Post-harvest regeneration surveys confirmed dominance of maple and birch. The golden-winged warbler was not yet observed, probably due to lack of advance regeneration. The yellow-breasted chat, a songbird that is a state species of concern, was observed using young regeneration. Additionally, deer populations have been managed on this property over the last 5 years through a Quality Deer Management Program.

Climate Change and the Hudson Farm Club

Climate Change Impacts

At the time of using the workbook, no climate change vulnerability assessment was available for northern New Jersey. Instead, a consulting forester from Gracie & Harrigan relied on global and regional technical input reports from the Intergovernmental Panel on Climate Change (2007), tree species habitat suitability modeling results from the Climate Change Tree Atlas (Landscape Change Research Group 2014), and other relevant primary and secondary literature. Projected changes in climate include:

- Warmer temperatures and drier soils during the summer
- Increased annual precipitation with a shift toward more-intense rain events and longer periods between events
- Increased disturbance from wind and storms.

These climatic changes are expected to affect forests in northern New Jersey. The Climate Change Tree Atlas projects declines in suitable habitat for many of the northern hardwood species, but also projects increases or stability in suitable habitat for oak and hickory species. Sugar maple, red maple, white ash, black cherry, American beech, and black birch are among the most common species on this property, and are all projected to lose suitable habitat. Species projected to increase include pignut hickory, bitternut hickory, mockernut hickory, shagbark hickory, white oak, and chinkapin oak. Some species that are currently rare or absent from northern New Jersey that are expected to have suitable habitat in the future are post oak, southern red oak, loblolly pine, slash pine, shortleaf pine, black hickory, and blackjack oak. Warmer temperatures and a shifting soil moisture regime are also expected to benefit invasive species such as autumn olive, ailanthus, garlic mustard, and bush honeysuckles. These species generally occupy a range of site conditions, and can outcompete seedlings and saplings, thus hindering the regeneration of native species.

Challenges and Opportunities for Management

Based on the projected impacts to the area, challenges and opportunities in meeting management objectives were identified. Overall, warmer and drier conditions are expected to favor species that are suited to warmer and drier conditions, which could reverse the ongoing transition from oak/hickory to northern hardwoods that has been occurring in this area in recent decades. Climate change-related challenges include the following:

- It may be difficult to maintain American beech in the future, although this species is currently an important mast species. Beech bark disease is currently a problem for beech, and this species is also projected to decline sharply as a result of climate change.
- It may be harder to maintain other northern hardwood species in this location because suitable habitat for many species is also projected to decrease.
- Insect pests and pathogens are expected to become more damaging as tree species respond to a variety of climate-related stressors. For example, oak species are at greater risk of total mortality when consecutive years of gypsy moth defoliation are combined with drought.

Climate change-related opportunities include the following:

- Warmer temperatures, drier soils, and more frequent drought are expected to create more-suitable conditions for the regeneration of oaks and hickories, which are currently not regenerating adequately.
- Successful regeneration of oak and hickory species would also provide important mast for wildlife in the absence of beech nuts.

Adapting to Climate Change

Approaches and Actions for Adaptation

Staff from Gracie & Harrigan Consulting Foresters used the Adaptation Workbook to identify actions to enhance the adaptive capacity of the property. A consulting forester first identified an overall approach to managing this stand under changing conditions: restoring the oak and hickory component of this forest while simultaneously reducing the northern hardwood component. Specific tactics were identified that, given anticipated challenges in maintaining northern hardwood species over the long term, support transition to an oak- and hickory-dominated forest while providing early successional habitat (Table 8, Figs. 21 and 22).

Table 8.—Selected proposed adaptation actions identified for the Hudson Farm Club adaptation demonstration in northern New Jersey

Management area/topic	Adaptation approach	Proposed adaptation tactics
Upland oak/ northern hardwood forest	Restore fire to fire-adapted ecosystems	Simulate low- to medium-intensity fire regime to stimulate or enhance oak regeneration and improve light conditions on the forest floor
		Perform intermediate treatment to reduce maple/ beech/birch seed sources and stimulate resprouting of the woody understory
	Prevent the introduction and establishment of invasive plant species, and remove existing invasive species	Conduct preharvest invasive plant control and increase frequency of monitoring and control
	Maintain or improve the ability of forests to resist pests and pathogens	Spray for gypsy moth to prevent two consecutive years of defoliation and reduce mortality of oaks during periods of drought

Figure 21.—Results of an intermediate stand treatment, which reduced the maple and beech component, and improved site conditions for oak regeneration, Hudson Farm Club demonstration site in northern New Jersey. Photo by Steve Kallesser, Gracie & Harrigan Consulting Foresters, Inc., used with permission.

Monitoring

Consulting foresters identified a number of potential monitoring metrics to evaluate the effectiveness of their adaptation strategies. For example, in harvested areas, the number of acres of successful oak and hickory regeneration will be measured at 1 and 3 years post-harvest. The number of gypsy moth egg casings per acre will be measured during the winter or fall following a season with widespread defoliation. A successful evaluation would confirm more species present in post-harvest stand survey than in the preharvest stand survey, with low occurrence of gypsy moth. Across the property, and larger northern New Jersey region, invasive species are expected to become a greater threat and require more resources. Although monitoring for invasive species is usually conducted 3 years post-harvest, an earlier and additional survey at 1 year post-harvest will improve chances of early detection.

More Information

A forest management plan for the Hudson Farm Club integrates the ideas that were generated by using the Adaptation Workbook. More information on this adaptation demonstration is available at www.forestadaptation.org/demonstration-projects/HudsonFarmClub.

Figure 22.—Resprouting of the woody understory, which will provide early successional habitat for wildlife in the short term, at the Hudson Farm Club demonstration site, New Jersey. Photo by Steve Kallesser, Gracie & Harrigan Consulting Foresters, Inc., used with permission.

Superior National Forest – North Shore Forest Restoration Project

Project Area and Management Goals

The forests along Minnesota's North Shore of Lake Superior (Fig. 23) are important for wildlife habitat, as regulators of stream temperatures, and as scenic elements of the North Shore. Tourists who make the drive along Scenic Highway 61 from Duluth to the Canadian border support a thriving recreation and tourism economy with many outfitters, restaurants, and lodges. Visitors and year-round residents have noticed a striking change in the landscape in the last few decades. Current stands of paper birch and aspen have reached their biological age limits and nearly 80 percent of the birch along the North Shore are old and dying (Fig. 24). In addition, conifer regeneration is nearly absent in the understory of North Shore forests due to a lack of mature trees to provide seed, increased competition from native bluejoint grass, and heavy deer browse. Both the decline of aspen and birch and the apparent lack of conifer regeneration have prompted attention and concern from many agencies and landowners in the region.

As a result, the Superior National Forest (SNF) is trying to restore forests in this landscape through active forest management. In 2013, SNF staff joined with the State of Minnesota, the Grand Portage Tribe, and a broader group of stakeholders

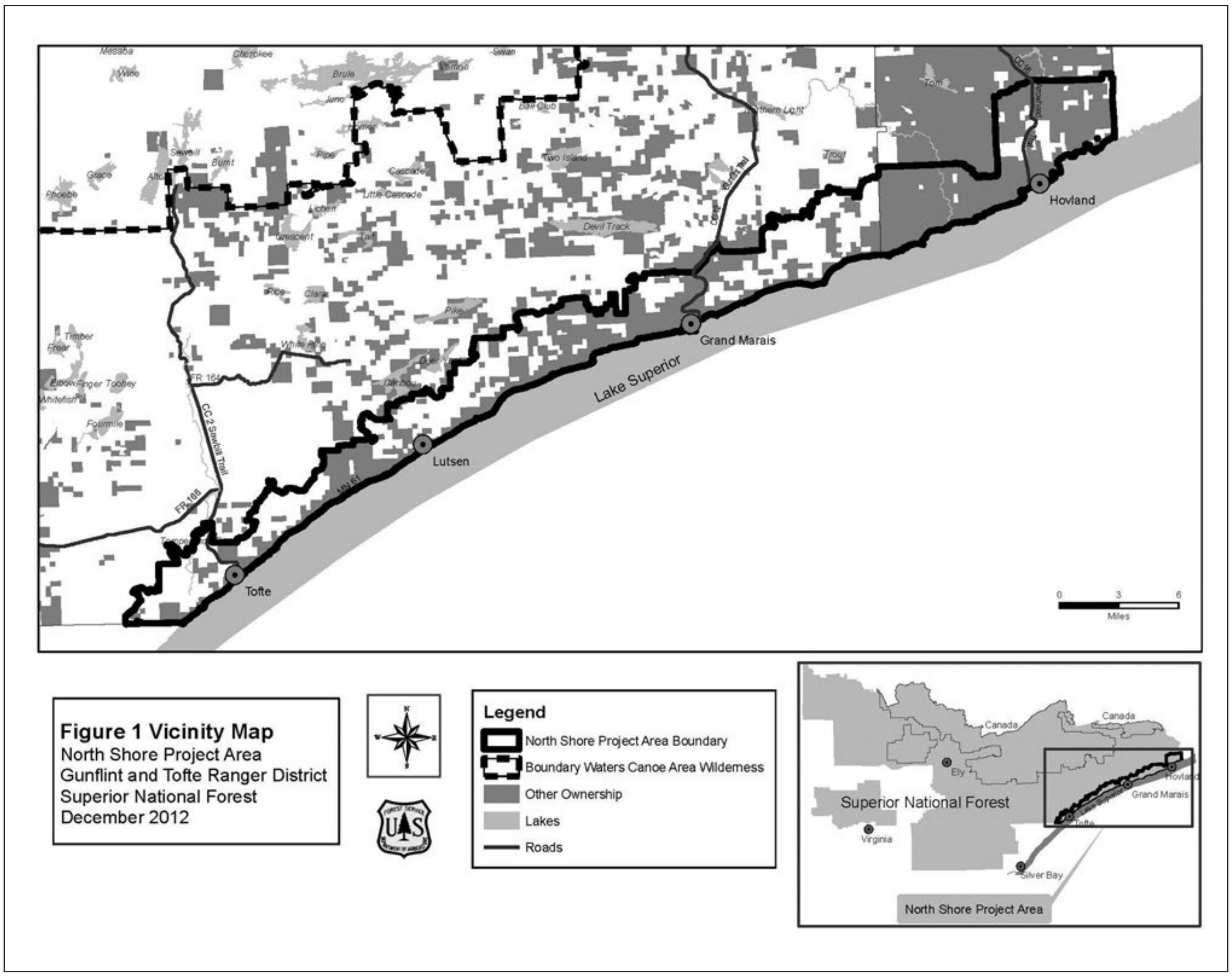


Figure 23.—The North Shore Forest Restoration Project location and surrounding area. Map prepared by the Superior National Forest.

Figure 24.—Stands of old and dying birch, with very little conifer regeneration in the understory, along the North Shore in Minnesota. Photo by the Superior National Forest.

called the North Shore Forest Collaborative (www.northshoreforest.org/) to create the North Shore Forest Restoration Project. All partners shared the primary concern of restoring eastern white pine, northern white-cedar, and other native plants to the area to ensure the health and resilience of the forest. The SNF North Shore Interdisciplinary Team designed restoration treatments for this adaptation demonstration that would occur on SNF lands only. The project area for the Forest Service North Shore Forest Restoration Project is about 102,000 acres, which is part of a larger North Shore Forest Collaborative boundary of more than 200,000 acres. Active management is planned for about 12,000 acres within the Forest Service ownership. This project was planned according to National Environmental Policy Act procedures used within the Forest Service.

Goals for the North Shore Forest Restoration Project include:

- Restoring native vegetation communities, including forests of paper birch and long-lived conifers
- Improving wildlife habitat, including cavities for nesting sites and coarse woody debris
- Improving watershed health, with a focus on riparian areas that drain into Lake Superior
- Ensuring a sustainable supply of timber products that provide an economic opportunity to local communities
- Reducing hazardous fuels to decrease wildfire risk.

Climate Change and the North Shore of Lake Superior

Climate Change Impacts

The SNF project team gathered information from the Minnesota Forest Ecosystem Vulnerability and Synthesis to capture large-scale trends and projections for northern Minnesota (Handler et al. 2014a). The team also considered how the local characteristics of the project area might modify some of the projected impacts of climate change. Northern Minnesota has experienced substantial changes in temperature and precipitation over the past 100 years, and the rate of change appears to be increasing (Handler et al. 2014a). A few climate trends relevant to the project area are:

- Temperatures have increased across northern Minnesota, with the greatest warming occurring during winter, and this trend is expected to continue. Temperature increases during the 20th century were greater along the North Shore of Lake Superior than in other parts of northern Minnesota.
- The North Shore project area received increased precipitation during the 20th century across all seasons, and heavy rainfall events became more frequent. Precipitation is projected to increase in winter and spring across a range of climate scenarios, but there is greater uncertainty for summer precipitation. Slight increases or large decreases are possible.
- Snowfall decreased across northern Minnesota over the past century and this trend is expected to continue, with more winter precipitation falling as rain.

In summary, these climate trends point to a future that is warmer and more variable, presenting greater stress for paper birch, white spruce, balsam fir, and other boreal species present in the area. The steep terrain and shallow soils along the North Shore make the area more susceptible to flooding from heavy rain events, as was experienced in the summer of 2012. At the same time, forests may also be at increased risk of moisture stress because the southern aspect, warmer conditions, thin soils, and longer growing season could combine to make water stress more challenging for forests in this landscape.

Challenges and Opportunities for Management

Based on the projected impacts to the area, project team members identified challenges and opportunities in meeting their management objectives. Examples of climate change-related challenges for forest restoration in the North Shore landscape are as follows:

- It may become more challenging to regenerate paper birch in the future as conditions change.
- Deer herbivory will be an obstacle for planning and regenerating many tree species because deer populations are expected to remain high.
- Many iconic tree species in the project area, such as white spruce, balsam fir, paper birch, and quaking aspen, are projected to decline in the future.
- Outbreaks of pests like spruce budworm may be larger and more damaging in the future.

Climate change-related opportunities for forest restoration in the North Shore landscape include the following:

- There may be a window remaining for regeneration of paper birch during the next 10 years, before conditions become more unfavorable.
- Lake Superior may moderate future changes. This landscape could provide one of the best long-term refugia for boreal species, compared to other parts of Minnesota.
- There are some north-facing and wetter microsites within the project area that may be better options for retaining boreal species over the long term.
- Eastern white pine is tolerant of a wide range of conditions and is projected to have increased suitable habitat. Red pine is also projected to increase in suitable habitat along the North Shore.

Adapting to Climate Change

Approaches and Actions for Adaptation

After going through the Adaptation Workbook, SNF staff continued to think about possible adaptation actions and refine the North Shore Forest Restoration Project (Table 9). Importantly, the team members recognized that many of the management actions they already had planned also had benefits for climate change adaptation. Northeastern Minnesota also has the potential to provide refugia for boreal species like paper birch and white spruce. Therefore, the team ultimately decided to proceed with many of the original goals and objectives of the project. Several modifications were added to the Proposed Action to increase diversity and future management flexibility.

Table 9.—Selected proposed adaptation actions identified for the North Shore Forest Restoration Project on the Superior National Forest in Minnesota

Management area/topic	Adaptation approach	Proposed adaptation tactics
Entire project	Maintain and create habitat corridors through reforestation or restoration	Consider spatial arrangement of treatments for connectivity and corridors
	Use landscape-scale planning and partnerships to reduce fragmentation and enhance connectivity	Work with neighboring landowners and the North Shore Forest Collaborative to connect treatment areas
	Manage herbivory to protect or promote regeneration Protect future-adapted regeneration from herbivory	Try a variety of strategies for protecting regeneration from deer herbivory, such as fences, tree cages, bud caps, or repellent sprays, or some combination
	Establish or encourage new mixes of native species	Plant additional native species that are present in the surrounding landscape that were not originally part of the project design, including bur oak and northern red oak
Paper birch	Anticipate and respond to species decline Favor or restore native species that are expected to be better adapted to future conditions	Identify stands of old, poor-quality paper birch for restoration to other appropriate native or climate-adapted forest types
	Prioritize and protect existing populations on unique sites	Identify the best possible locations to retain paper birch on the landscape for the long term, including stands of healthy paper birch, areas with north-facing slopes, and cold pockets
Eastern white pine	Manage for species and genotypes with wide moisture and temperature tolerances Favor or restore native species that are expected to be better adapted to future conditions Manage habitats over a range of sites and conditions	Increase the proportion of planted eastern white pine, and plant this species within many other topographic positions and forest types

Adding these adjustments to the original Proposed Action will help the Superior National Forest restore forest cover along the North Shore, and accomplish the objectives of restoring native vegetation communities, improving wildlife habitat, improving watershed health, providing sustainable timber products, and reducing hazardous fuels.

Monitoring

Project team members identified several monitoring items routinely applied or required on Forest Service vegetation management projects that would deliver important information about the effectiveness of adaptation actions. For example, standard silvicultural exams will provide information about the number of trees per acre by species, basal area, and size classes. These surveys can give managers a sense of the number of species or the volume within a stand that may be composed of species at risk of declining over time. Similarly, stocking surveys are routinely implemented during the first and third years after planting. It may be possible to add another survey at this time for the subset of future-adapted or off-site species to compare their success to more conventional species.

After completing the Adaptation Workbook and subsequent project planning, the SNF decided that the North Shore Forest Restoration Project will be managed according to an adaptive management framework. This means that treatments are designed with built-in continuous assessment and processes for improvement (i.e., "If X happens, then action Y will be implemented."). This approach will allow managers the latitude to treat successive portions of the project based on local conditions, and to learn from activities implemented in early years of the project.

More Information

A final Decision Notice was issued for the North Shore Forest Restoration Project in August 2014. More information about the final decision and planned actions is available on the Superior National Forest Web site (http://go.usa.gov/SyVz). Implementation of the project began in 2014 and will continue for the next several years. More information on this adaptation demonstration is available at www.forestadaptation.org/NorthShore.

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APPENDIX 1. Synthesis of Adaptation Strategies and Approaches

The adaptation strategies and approaches described in Chapter 3 of this document provide a menu of strategies and approaches for adapting forest ecosystems to climate change. These strategies and approaches serve as stepping stones to enable natural resource managers to translate broad concepts into targeted and prescriptive tactics for implementing adaptation (Janowiak et al. 2010). For the updated menu used in this document, we expanded our geographic extent to the Midwest and Northeast, and extended our consideration to the major forest types within those regions. The methods and processes used to develop and refine this menu are described in this appendix.

Synthesis of Adaptation Actions

This menu of adaptation strategies, approaches, and example tactics builds on the menu that was originally published in Swanston and Janowiak (2012) and compiled from a number of sources in both peer-reviewed and gray literature. We also used the BioOne®, Google Scholar, and TreeSearch search engines to conduct additional literature searches for peer-reviewed and gray literature that had been published in the last 3 years. Key words included climate change, adaptation, forest management, adaptive management, impacts, migration, and genetic conservation. A list of key literature used is presented in Table 10. Additional actions were identified from contemporary literature and recent case studies of forest adaptation projects, such as those found at www.forestadaptation.org/demonstrations. The adaptation concepts and actions compiled from the literature and case studies were organized into a hierarchy of adaptation actions from broad concepts to specific tactics (see Figure 5 in Chapter 2). Based on expert review (see next section), adaptation actions were refined and organized into 10 strategies, 36 approaches, and more than 100 example tactics.

Expert Comment Process

We drew upon the experience and expertise of scientists, adaptation experts, and forest managers for input on how this expanded menu of adaptation strategies and approaches relates to forest types across ecological provinces in the Midwest and Northeast (Tables 11 and 12). We compiled a list of individuals with expertise in forest ecology and management in the region, seeking representation from a variety of geographies and a balance of science and management from a range of institutions (Table 13). Expertise was determined by publications related to key words, as well as previous experience working in a region or forest type. Overall, 42 experts provided feedback, with at least two experts commenting from each ecological province.

We elicited comments from experts by using an online questionnaire that asked each person to evaluate all of the adaptation strategies and approaches for a single forest type. A draft chapter of the revised strategies and approaches was provided. Before beginning the review, experts were asked to think about potential climate change impacts that are most important to the ecological province that they would be considering. We provided a list of existing climate change vulnerability assessments and impact reports that they could use for reference.

For each adaptation strategy, experts were first asked a set of questions about the applicability of each adaptation approach under that strategy for their assigned forest type and region. Experts were

Table 10.—Literature reviewed for compilation of adaptation strategies and approaches. Full citations for these resources are in the Literature Cited section of this document

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Nitschke, C.R.; Innes, J.L. 2008. **Integrating climate change into forest management in south-central British Columbia: an assessment of landscape vulnerability and development of a climate-smart framework.**

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(Continued on next page)

Table 10 (continued).

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Spittlehouse, D.L.; Stewart, R.B. 2003. **Adaptation to climate change in forest management.**	Wilkerson, E.; Whitman, A. 2011. **Climate change & forests: What can we expect? What can we do about it?**
	Yaussy, D.A.; Iverson, L.R.; Matthews, S.N. 2013. **Competition and climate affects US hardwood-forest tree mortality.**

Table 11.—Number of reviewers for each ecological province in the Midwest and Northeast

Province	Province name	Acres	Number of reviewers
212	Laurentian Mixed Forest	64,486,516	20
222	Midwest Broadleaf Forest Province	91,504,442	17
221	Eastern Broadleaf Forest	50,063,685	12
223	Central Interior Broadleaf Forest	43,500,974	10
251	Prairie Parkland	88,787,652	10
211	Northeastern Mixed Forest	33,980,801	8
M211	Adirondack-New England Mixed Forest-Coniferous Forest-Alpine Meadow	24,404,254	7
M221	Central Appalachian Broadleaf Forest-Coniferous Forest-Meadow	20,713,304	4
232	Outer Coastal Plain Mixed Forest	7,721,043	3
234	Lower Mississippi Riverine Forest	2,656,565	2
231	Southeastern Mixed Forest	367,860	2

Table 12.—Forest and forest ecosystem types represented by reviewers' expertise

Forest type or forest ecosystem	Forest type or forest ecosystem
Allegheny hardwoods	Mixed oak
Aspen	Mixed pine
Aspen-paper birch	Northern hardwoods
Bottomland hardwoods	Oak savanna and woodland
Central hardwoods	Oak-hickory
Coastal plain pine-hardwoods	Oak-pine
Dolomite glade	Peatlands (forested)
Dry oak heath	Pine-oak barrens
Flatwoods	Red spruce
Floodplain forest	Riverine forest
Hemlock	Shortleaf pine
Jack pine	Southern hardwoods
Limestone glade and barrens	Spruce-fir (boreal and montane)
Loblolly pine	Tallgrass prairie
Loblolly-shortleaf pine	Upland black spruce
Longleaf pine	Urban hardwoods
Lowland conifer	Wetlands (forested)
Lowland hardwoods	White pine
Mixed mesophytic hardwoods	

Table 13.—Name and affiliation of experts participating in the review process, listed alphabetically by last name

RespondentID	Name	Organization
2501616594	Scott Bearer	The Nature Conservancy
2466763305	Tara Bergeson	Wisconsin Department of Natural Resources
2465358976	Don Bragg	U.S. Forest Service, Southern Research Station
2460741669	Diane Burbank	U.S. Forest Service, Green Mountain and Finger Lakes National Forests
2460156915	Andrew Burton	Michigan Technological University, School of Forest Resources and Environmental Science
2458772630	Greg Corace	U.S. Fish and Wildlife Service, Seney National Wildlife Refuge
	Abigail Derby Lewis	The Field Museum and Chicago Wilderness
2458498047	Dan Dey	U.S. Forest Service, Northern Research Station
2458456740	George F. Frame	Society for the Protection of New Hampshire Forests
2458018735	Lee Frelich	University of Minnesota, Department of Forest Resources
2457977386	Susan Galatowitsch	University of Minnesota, Department of Fisheries, Wildlife and Conservation Biology
2456799239	Erica Hahn	U.S. Forest Service, Superior National Forest
2455969424	Robert G. Haight	U.S. Forest Service, Northern Research Station
2454659604	Beth Hardman	U.S. Forest Service, Mark Twain National Forest
2454440654	Dawn Henderson	Missouri Department of Conservation
2453270684	Brad Hutnik	Wisconsin Department of Natural Resources, Division of Forestry
2451946637	John Kabrick	U.S. Forest Service, Northern Research Station
2451074763	Kent Karriker	U.S. Forest Service, Monongahela National Forest
2450434996	William S. Keeton	University of Vermont, Rubenstein School of Environment and Natural Resources
2449659075	Benjamin Knapp	University of Missouri, School of Natural Resources
2449008261	Rose-Marie Muzika	University of Missouri, School of Natural Resources
2448789985	Christian Nelson	Fond du Lac Band of Lake Superior Chippewa
2447619854	David Neumann	Michigan Department of Natural Resources, Forest Resources Division
2447372748	Greg Nowacki	U.S. Forest Service, Eastern Region
2447232755	Brian Palik	U.S. Forest Service, Northern Research Station
2445749238	Linda Parker	U.S. Forest Service, Chequamegon-Nicolet National Forest
2445004553	Judi Perez	U.S. Forest Service, Hoosier National Forest
	Ann Pierce	Minnesota Department of Natural Resources, Division of Ecological and Water Resources
2443096734	Charles Ruffner	Southern Illinois University-Carbondale, Department of Forestry
2442974255	Lindsey Rustad	U.S. Forest Service, Northern Research Station
2441726031	Gregor Schuurman	Wisconsin Department of Natural Resources, Bureau of Endangered Resources
2440156915	K. Rogers Simmons	U.S. Forest Service, White Mountain National Forest
2438661117	Matthew St. Pierre	U.S. Forest Service, Chequamegon-Nicolet National Forest
2438640191	Susan Stout	U.S. Forest Service, Northern Research Station
2433223991	Esther D. Stroh	U.S. Geological Survey
2432921593	John B. Taft	University of Illinois at Urbana-Champaign, Prairie Research Institute, Illinois Natural History Survey
2432105714	Chris Thornton	U.S. Forest Service, Hoosier National Forest
2428553992	Eric Ulaszek	U.S. Forest Service, Midewin National Tallgrass Prairie
2427998214	Laura Watts	U.S. Forest Service, Mark Twain National Forest
2425112578	Mark White	The Nature Conservancy in Minnesota and the Dakotas
2421356782	Sandy Wilmot	Vermont Department of Forests, Parks and Recreation

then asked to consider how effectively the suite of approaches helped support the broader strategy. The questions were open-ended to allow reviewers to comment freely. Experts were asked to evaluate every strategy and every approach and to provide examples of adaptation actions that apply to their forest type or ecological province (i.e., example tactics). If the expert determined that a strategy or approach was useful in the forest type considered, he or she was asked to provide a rationale.

The instructions to the experts are reproduced on the next two pages (with deadline and project coordinator's contact information omitted). Use of the online questionnaire enabled us to easily manage a large amount of feedback. However, some experts chose not to use the questionnaire and provided comments in a Microsoft® Word document.

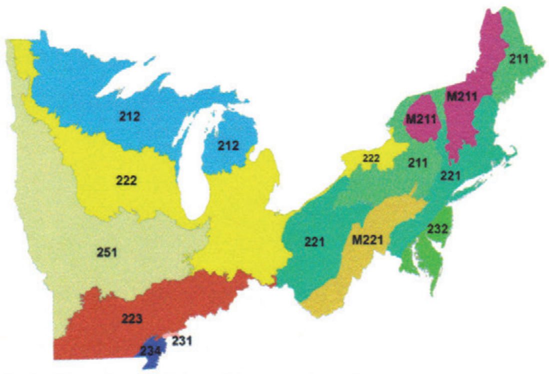
Experts were given about 1 month to respond. After the deadline, responses were collated by strategy, then by approach; and comments from multiple reviewers were listed together. Responses for all approaches and strategies were evaluated and incorporated into chapter revisions that clarified adaptation actions, reorganized adaptation concepts, and identified new examples of tactics that might be applied in a specific place to meet specific management objectives.

Red pine needles in the Upper Peninsula, Michigan. Photo by Kailey Marcinkowski, Michigan Technological University, used with permission.

Information for the Review of Adaptation Strategies & Approaches Survey

Thank you for your willingness to review a new version of "Adaptation Strategies and Approaches!" "Adaptation Strategies and Approaches" comprises one chapter of *Forest Adaptation Resources: Tools and Approaches for Land Managers* (FAR), a climate adaptation resource that has been developed through the Climate Change Response Framework. We are revising the FAR document, including the "Adaptation Strategies and Approaches" chapter, to increase the availability and usability of this tool across the Midwest, Mid-Atlantic, and Northeast.

The goal of this review is to capture your expertise and help us better understand how adaptation actions could be applied in different forest ecosystems across a variety of geographic regions (see map below). Information collected from this survey will be used to revise the adaptation strategies and approaches so they are applicable to forest ecosystems across the Midwest, Mid-Atlantic, and Northeast. Information about the document, survey goals, and review methodology is provided below. **We hope you will be able to complete the review by [date].**



Ecological Provinces of the Midwest, Mid-Atlantic, and Northeast U.S. See McNab et al. 2007 for descriptions.

Adaptation Strategies and Approaches

There is a wealth of literature on climate change adaptation, but most of it is quite broad and not very useful at scales most relevant to land managers. The FAR document focuses on forest ecosystems and provides managers with practical, relevant adaptation approaches that can be incorporated into planning and decision-making. There are two interrelated chapters of the FAR document that help achieve this intent. The "Adaptation Strategies and Approaches" chapter lays out a menu of tiered adaptation actions designed for natural resource professionals, including managers and planners. The "Adaptation Workbook" chapter walks managers through a process to consider their management objectives, climate change impacts, adaptation strategies and approaches, and management actions to adapt forests to a changing climate.

We have compiled a list of adaptation actions from peer-reviewed literature, gray literature, expert review, and feedback from managers who have used the adaptation workbook. We then organized these into a tiered menu of available adaptation actions that includes

- ***Options*** – the foundational concepts of resistance, resilience, and response
    - ***Strategies*** – broad adaptation responses that consider regional ecosystem types and conditions
        - ***Approaches*** – detailed adaptation responses influenced by site conditions and management goals
            - ***Tactics*** – prescriptive actions designed by managers to account for site-level conditions and management objectives.

In the revised version, we have described a variety of strategies and approaches in the context of regional forest ecosystems. For each approach, we have also provided several examples of tactics that could potentially be used to implement that approach. These examples are provided to facilitate brainstorming, and are not meant to serve as recommendations or a comprehensive list. Actual tactics are intended to be designed by the land manager, using their knowledge of a specific location and management context. We would especially like your feedback on how well that idea is conveyed, or if there are better examples we should provide.

(continued on next page)

Survey details

We have created a survey to walk you through the process of evaluating the "Adaptation Strategies and Approaches" chapter. In asking you to complete the survey, we want to draw upon your experience and expertise to help us understand how these strategies and approaches relate to the forested ecosystems in which you live and work. For the purposes of this document, we define forest ecosystems as systems that contain some component of tree canopy. They include closed-canopy forests, as well as more open woodlands and savannas. Please consider all the forest types you work in when thinking about applying each approach. The survey is available at: www.surveymonkey.com/s/strategies-approaches [note: link is no longer available].

Before beginning the survey, we recommend that you spend some time thinking about potential climate change impacts that are most important to the ecosystems in the region you will be considering. There are several assessments of potential climate change impacts on regional ecosystems, including:

- Ecosystem vulnerability assessment and synthesis for northern Wisconsin (especially Tables 3 and 8)
- Climate change vulnerabilities within the forestry sector for the Midwestern United States. In: *U.S. National Climate Assessment Midwest Technical Input Report*.
- Confronting climate change in the Great Lakes region (reports are available for IL, IN, MI, MN, NY, OH, PA, and WI).
- Changing climate, changing forests: The impacts of climate change on forests of the northeastern United States and eastern Canada (covers CT, MA, ME, NH, NY, RI, VT)

We have provided a draft of the "Adaptation Strategies and Approaches" chapter, and we recommend reading it beforehand and having it available as you enter your survey responses. In the survey, you will answer a series of questions for each strategy and approach.

For each strategy:

1. How well does the strategy and supporting text clearly describe the possible adaption action?
2. Can the strategy be implemented in the forest ecosystems where you work? If not, why?
3. Can you recommend publications that support this strategy?

For each approach:

1. How well does the approach and supporting text clearly describe the possible adaption action?
2. Can the approach be implemented in the forest ecosystems where you work? If not, why?
3. Can you recommend publications that support this approach?
4. Do the example tactics provide a sense of how this approach could possibly be implemented?
5. Do you know of specific examples where this approach has been implemented?

When filling out the survey, please keep the following things in mind:

- The actual implementation of strategies, approaches, and tactics are highly dependent upon location, site conditions, management objectives, anticipated climate change impacts, and other factors. You may need to use your imagination to comment on how well these actions would work in your region.
- While there are social, economic, and other constraints that would influence implementing an action, we only want to focus on the how well the action benefits the ecosystem. Please do not discount any options that you think are not socially or economically viable.
- Please evaluate every strategy and every approach. If a strategy or approach is not likely to be useful in the forest type you are considering, we would like to know why it does not work.

We think that the survey will take a few to several hours to complete. Please take as much time as you can. The online survey (www.surveymonkey.com/s/strategies-approaches) will save your answers if you wish to leave and complete it at a later time. **We hope you will be able to complete the survey by [date].** If you have any questions, or you need additional time, please contact [project coordinator].

APPENDIX 2: Common and Scientific Names of Species Mentioned in this Document

FLORA

Common name	Scientific name
fir spp.	*Abies* spp.
balsam fir	*Abies balsamea*
maple	*Acer* spp.
red maple	*Acer rubrum*
silver maple	*Acer saccharinum*
sugar maple	*Acer saccharum*
ailanthus	*Ailanthus altissima*
garlic mustard	*Alliaria petiolata*
birch spp.	*Betula* spp.
yellow birch	*Betula alleghaniensis*
black birch	*Betula lenta*
paper birch	*Betula payrifera*
bluejoint grass	*Calamagrostis canadensis*
hickory	*Carya* spp.
bitternut hickory	*Carya cordiformis*
pignut hickory	*Carya glabra*
shagbark hickory	*Carya ovata*
black hickory	*Carya texana*
mockernut hickory	*Carya tomentosa*
chestnut	*Castanea* spp.
American yellowwood	*Cladastris kentukea*
glade coneflower	*Echinacea simulata*
autumn olive	*Elaeagnus umbellata*
beech	*Fagus* spp.
American beech	*Fagus grandifolia*
white ash	*Fraxinus americana*
blue ash	*Fraxinus quadrangulata*
Kentucky coffeetree	*Gymnocladus dioica*
eastern redcedar	*Juniperus virginiana*
tamarack	*Larix laricina*
sericea lespedeza	*Lespedeza cuneata*
privet	*Ligustrum vulgare*
tuliptree	*Liriodendron tulipifera*
bush honeysuckles	*Lonicera* spp.
southern blazing star	*Mentzelia lindleyi*
Japanese stiltgrass	*Microstegium vimineum*
spruce spp.	*Picea* spp.
white spruce	*Picea glauca*
black spruce	*Picea mariana*
red spruce	*Picea rubens*
pine spp.	*Pinus* spp.
jack pine	*Pinus banksiana*
shortleaf pine	*Pinus echinata*
slash pine	*Pinus elliottii*
longleaf pine	*Pinus palustris*
red pine	*Pinus resinosus*

FLORA (continued)

Common name	Scientific name
eastern white pine	*Pinus strobus*
loblolly pine	*Pinus taeda*
aspen	*Populus* spp.
quaking aspen	*Populus tremuloides*
black cherry	*Prunus serotina*
kudzu	*Pueraria montana*
oak	*Quercus* spp.
white oak	*Quercus alba*
swamp white oak	*Quercus bicolor*
scarlet oak	*Quercus coccinea*
southern red oak	*Quercus falcata*
bur oak	*Quercus macrocarpa*
blackjack oak	*Quercus marilandica*
chinkapin oak	*Quercus muehlenbergii*
northern red oak	*Quercus rubra*
post oak	*Quercus stellata*
black oak	*Quercus velutina*
European buckthorn	*Rhamnus cathartica*
black locust	*Robinia pseudoacacia*
northern white-cedar	*Thuja occidentalis*
eastern hemlock	*Tsuga canadensis*
American elm	*Ulmus americana*

FAUNA

Common name	Scientific name
hemlock woolly adelgid	*Adelges tsugae*
moose	*Alces americanus*
Asian longhorned beetle	*Anoplophora glabripennis*
cattle	*Bos* spp.
spruce budworm	*Choristoneura fumiferana*
southern pine beetle	*Dendroctonus frontalis*
yellow-breasted chat	*Icteria virens*
gypsy moth	*Lymantria dispar*
Indiana bat	*Myotis sodalis*
white-tailed deer	*Odocoileus virginiana*
rabbit	*Oryctolagus cuniculus*
prairie warbler	*Setophaga discolor*
Kirtland's warbler	*Setophaga kirtlandii*
feral hog	*Sus scrofa*
black bear	*Ursus americanus*
golden-winged warbler	*Vermivora chrysoptera*

APPENDIX 3. Lead Authors and Other Contributors to Chapter 4

Lead Authors

Abigail Derby Lewis, senior conservation ecologist, the Field Museum

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Claire Woolley, founder, AddATree

APPENDIX 4. Adaptation Workbook: Short Version

This short version of the Adaptation Workbook provides a streamlined set of considerations using the adaptation process that is described in Chapter 5 of this document. It is intended for users who are familiar with the process and the anticipated effects of climate change in the area in which they work. It can also be used to collect notes and ideas that will be integrated into the comprehensive version of the workbook found in Chapter 5.

Step 1: DEFINE location, project, and time frames.

What are your management goals and objectives for the project area?

The first step is to describe the project area and your management objectives before considering the potential effects of climate change. This may include identifying:

- Any ecosystem types, stands, or other distinct areas that you want to consider individually
- Any short- or long-term milestones that can be used to evaluate progress.

Step 2: ASSESS site-specific climate change impacts and vulnerabilities.

What climate change impacts and vulnerabilities are most important to this particular site?

Climate change will have a wide variety of effects on the landscape, and not all places will respond similarly. List site-specific factors that may increase or reduce the effects of climate change in your project area, such as:

- Site conditions, such as topographic position, soils, or hydrology
- Past and current management
- Forest composition and structure
- Susceptibility to pests, diseases, or other stressors that may increase.

You can consult vulnerability assessments for information on the anticipated effects of climate change on forest ecosystems in a particular region. Select assessments are listed under "Resources" at www.adaptationworkbook.org.

Step 3: EVALUATE management objectives given projected impacts and vulnerabilities.

What management challenges and opportunities may occur as a result of climate change?

This step explores management challenges and opportunities that may arise under changing conditions. For each of your management objectives, consider:

- Management challenges and opportunities given the climate impacts you identified previously
- The feasibility of meeting each management objective under current management
- Other considerations (e.g., administrative, legal, or social considerations) beyond climate change that may affect your ability to meet your management objectives.

Do any of your management objectives need to change, given the projected climate impacts listed above?

☐ Yes ☐ No

If yes, adjust management objectives before proceeding to the next step.

Step 4: IDENTIFY adaptation approaches and tactics for implementation.

What actions can enhance the ability of the ecosystem to adapt to anticipated changes and meet management goals?

Generate a list of adaptation tactics—prescriptive actions specifically designed for your project area or property and your unique management objectives. Use the menu of Adaptation Strategies and Approaches (Box 18) as a starting point for identifying specific management tactics (e.g., what, how, when) that you can implement. As you develop tactics, consider the

- Benefits, drawbacks, and barriers associated with each tactic
- Effectiveness and feasibility of each tactic.

Box 18

Menu of Adaptation Strategies and Approaches

Strategy 1: Sustain fundamental ecological functions.

1.1. Reduce impacts to soils and nutrient cycling.
1.2. Maintain or restore hydrology.
1.3. Maintain or restore riparian areas.
1.4. Reduce competition for moisture, nutrients, and light.
1.5. Restore or maintain fire in fire-adapted ecosystems.

Strategy 2: Reduce the impact of biological stressors.

2.1. Maintain or improve the ability of forests to resist pests and pathogens.
2.2. Prevent the introduction and establishment of invasive plant species and remove existing invasive species.
2.3. Manage herbivory to promote regeneration of desired species.

Strategy 3: Reduce the risk and long-term impacts of severe disturbances.

3.1. Alter forest structure or composition to reduce risk or severity of wildfire.
3.2. Establish fuelbreaks to slow the spread of catastrophic fire.
3.3. Alter forest structure to reduce severity or extent of wind and ice damage.
3.4. Promptly revegetate sites after disturbance.

Strategy 4: Maintain or create refugia.

4.1. Prioritize and maintain unique sites.
4.2. Prioritize and maintain sensitive or at-risk species or communities.
4.3. Establish artificial reserves for at-risk and displaced species.

Strategy 5: Maintain and enhance species and structural diversity.

5.1. Promote diverse age classes.
5.2. Maintain and restore diversity of native species.
5.3. Retain biological legacies.
5.4. Establish reserves to maintain ecosystem diversity.

Strategy 6: Increase ecosystem redundancy across the landscape.

6.1. Manage habitats over a range of sites and conditions.
6.2. Expand the boundaries of reserves to increase diversity.

Strategy 7: Promote landscape connectivity.

7.1. Reduce landscape fragmentation.
7.2. Maintain and create habitat corridors through reforestation or restoration.

Strategy 8: Maintain and enhance genetic diversity.

8.1. Use seeds, germplasm, and other genetic material from across a greater geographic range.
8.2. Favor existing genotypes that are better adapted to future conditions.

Strategy 9: Facilitate community adjustments through species transitions.

9.1. Favor or restore native species that are expected to be adapted to future conditions.
9.2. Establish or encourage new mixes of native species.
9.3. Guide changes in species composition at early stages of stand development.
9.4. Protect future-adapted seedlings and saplings.
9.5. Disfavor species that are distinctly maladapted.
9.6. Manage for species and genotypes with wide moisture and temperature tolerances.
9.7. Introduce species that are expected to be adapted to future conditions.
9.8. Move at-risk species to locations that are expected to provide habitat.

Strategy 10: Realign ecosystems after disturbance.

10.1. Promptly revegetate sites after disturbance.
10.2. Allow for areas of natural regeneration to test for future-adapted species.
10.3. Realign significantly disrupted ecosystems to meet expected future conditions.

Step 5: MONITOR and evaluate effectiveness of implemented actions.

What information can be used to evaluate whether the selected actions were effective and to inform future management?

Monitoring metrics can help you determine whether you are making progress on your management goals and evaluate the effectiveness of those actions. When identifying monitoring items, work to identify monitoring items that:

- Can tell you whether you have achieved your management goals and objectives
- Can tell you whether the adaptation tactics had the intended effect
- Are realistic to implement.

APPENDIX 5. Adaptation Workbook: Blank Worksheets

Step 1 Worksheet

Project Area or Property:		Location:	
Ecosystem Type or Management Topic	Management Goals	Management Objectives	Time Frames

Step 2 Worksheet

Ecosystem Type or Management Topic (from Step 1)	Regional Climate Change Impacts and Vulnerabilities	Climate Change Impacts and Vulnerabilities for the Project Area or Property	Vulnerability Determination

Step 3 Worksheet

Ecosystem Type or Management Topic (from Step 1)	Management Objectives (from Step 1)	Challenges to Meeting Management Objective with Climate Change	Opportunities for Meeting Management Objective with Climate Change	Feasibility of Meeting Management Objective under Current Management	Other Considerations

Slow down to consider…

Step 4 Worksheet

Ecosystem Type or Management Topic (from Step 1)	Adaptation Actions		Time Frames	Benefits	Drawbacks and Barriers	Practicability of Tactic	Recommend Tactic?
	Approach	Tactic					

Step 5 Worksheet

Ecosystem Type or Management Topic (from Step 1)	Adaptation Monitoring Variable	Criteria for Evaluation	Monitoring Implementation

APPENDIX 6. Adaptation Workbook: Example Worksheets

A more complete set of information is provided in Tables 14 through 18 for the Jerktail Mountain adaptation demonstration (see Chapter 6, pp. 95-97, for a description of the demonstration).

Table 14.—Example of a completed Step 1 worksheet for the Adaptation Workbook, drawn from the Jerktail Mountain adaptation demonstration (described in Chapter 6)

Project Area or Property: Jerktail Mountain glade and woodland		**Location:** Jerktail Mountain management unit, Pioneer Forest and Ozark National Scenic Riverway, 9 miles northeast of Eminence, Shannon County, Missouri	
Ecosystem Type or Management Topic	**Management Goals**	**Management Objectives**	**Time Frames**
All forest types	Improve natural community health and resilience. Provide timber products.	Use selective timber thinning and prescribed fire to achieve management goals.	Ongoing.
Igneous and dolomite glades	Restore glade natural communities.	Restore glade communities using prescribed fire of variable intensity (higher on igneous glades; lower in wetter, more protected areas) once every 3-4 years in beginning. Move to 5-year rotation after four to five entries. Reduce negative human impacts on sites (e.g., ATVs, horses). Reduce eastern redcedar encroachment. Monitor and treat invasive exotic species if feasible (e.g., hogs, plants), potentially using late summer burns (moisture-of-extinction burns).	Prescribed burns every 3-4 years initially, switching to every 5 years once established.
Woodland	Restore woodland to more natural conditions.	Reduce eastern redcedar encroachment. Variable-intensity prescribed fire once every 3-4 years in beginning; move to 5-year rotation after four to five entries. Increase component of fire-tolerant species including shortleaf pine, white oak, post oak, and chinkapin oak. Thin timber; stand density will be variable based on site conditions across the landscape (aspect, soil type).	Prescribed burns every 3-4 years initially, switching to every 5 years once established. Harvest every 20-30 years.

Table 15.—Example of a completed Step 2 worksheet for the Adaptation Workbook, drawn from the Jerktail Mountain adaptation demonstration (described in Chapter 6). *Regional Climate Change Impacts and Vulnerabilities information was drawn from Brandt et al. (2014).

Ecosystem Type or Management Topic	Regional Climate Change Impacts and Vulnerabilities*	Climate Change Impacts and Vulnerabilities for the Project Area or Property	Vulnerability Determination
All forest types	Temperatures: warmer temperatures and longer growing seasons (especially warmer winter lows); more extremely hot days. Precipitation: wetter springs, heavy precipitation events. Winter conditions: less snow and freezing rain, reduced periods of frozen soil. Drier soil later in the growing season. Greater risk of wildfire. Exacerbation of oak decline. Increase in new and existing invasive plant species (kudzu, privet, Japanese stiltgrass, sericea lespedeza). Risk of southern pine beetle expanding into Missouri. See Chapter 6 of Brandt et al. (2014) for more details.	Oak decline is not as much of an issue on Pioneer Forest due to a history of uneven-aged management. Sericea lespedeza is currently the major nonnative invasive species of issue on these sites.	
Igneous and dolomite glades	Although future distribution of these nonwoody species has not been modeled, many are adapted to the hot, dry conditions that are expected to become more common. Despite this, a number of modeling studies in other areas have shown that species with narrow geographic distributions, like many glade-associated species, are more at risk to climate change. Post oak is typically found in glade systems, and is likely to increase. Eastern redcedar invasion has led to this species becoming a dominant species in glades, and it is likely to expand in the future due to other factors besides climate change.	Eastern redcedar encroachment is the main issue negatively affecting herbaceous species on glades at this site; some removal may be needed. Sericea lespedeza invasion is a local issue that also may need to be addressed. Reduction in human disturbance would reduce the risk of invasion of sericea lespedeza. Some removal may be needed in sites already invaded. In general, system is well positioned to respond favorably to management planned for the area. There is a wide diversity of herbaceous species already present or in the seed bank.	Low. Current management and species composition help reduce risks to the area.

Table 15 (continued).

Ecosystem Type or Management Topic	Regional Climate Change Impacts and Vulnerabilities*	Climate Change Impacts and Vulnerabilities for the Project Area or Property	Vulnerability Determination
Woodland	Many tree species in this community type are projected to do better under future climate conditions, such as shortleaf pine, blackjack and post oak, and black hickory. Changes in black, chinkapin, and scarlet oak may depend on whether summer precipitation increases or decreases. Although white oak is projected to decline slightly based on temperature and precipitation alone, its tolerance to drought and fire would be expected to allow it to persist. Eastern redcedar, which outcompetes herbaceous vegetation and limits pine regeneration, is projected to remain relatively stable under future climate changes and could expand for other reasons Oak decline is likely to remain a threat to black and scarlet oak. Oak decline may become a larger threat to trees that become stressed by an increased duration and extent of drought conditions, which appear to be more likely under the GFDL A1FI scenario. See Chapter 2 in Brandt et al. (2014) for more information about general circulation models and scenarios.	Shortleaf pine, which is less prevalent on the site, is projected to do well under a range of climate scenarios. However, it will regenerate only on bare mineral soil in an open area. Therefore, it will do well only if conditions are established to allow regeneration. Southern pine beetle could be a potential future risk for shortleaf pine, but prescribed fire and reduction in stand density through timber thinning could reduce risk of pine beetle attack. Post oak, another common species on the site, is projected to do well under a range of scenarios. White oak and black oak, which are also common on the site, should generally do well, but Tree Atlas suggests a slight decline in habitat suitability under a harsher climate/emissions scenario. Scarlet oak, a species that is currently common on the site, is projected to be negatively affected under both scenarios. Chinkapin oak, which is more prevalent on this site than on the pine site, may be negatively affected under high emissions scenario, positively under low emissions scenario. Northern red oak is also more common on this site than on the pine site and is projected to be negatively affected by warmer temperatures, especially if summers become drier. Eastern redcedar encroachment may continue to be an issue at this site. Lower risk of pine beetle outbreaks due to a more open structure and less of a pine component than at the shortleaf pine site. Clay content is higher at this site (soils are less permeable).	Low. Current management and species composition help reduce risks to the area.

Table 16.—Example of a completed Step 3 worksheet for the Adaptation Workbook, drawn from the Jerktail Mountain adaptation demonstration (described in Chapter 6)

Ecosystem Type or Management Topic	Management Objectives (from Step 1)	Challenges to Meeting Management Objective with Climate Change	Opportunities for Meeting Management Objective with Climate Change	Feasibility of Meeting Management Objective under Current Management	Other Considerations
Igneous and dolomite glades	Restore glade communities using prescribed fire of variable intensity (higher on igneous glades; lower in wetter, more protected areas) once every 3-4 years in beginning. Move to 5-year rotation after four to five entries. Reduce negative human impacts on sites (e.g., ATVs, horses). Reduce eastern redcedar encroachment. Monitor and treat invasive exotics as feasible (e.g., hogs, plants), potentially using late summer burns (moisture-of-extinction burns).	More winter moisture will mean that glades will be harder to burn than the woodlands. Glades can act like a wet sponge in the spring. It could be difficult to control or reduce eastern redcedar with fire alone; mechanical treatment for eastern redcedar may be needed.	Moisture-of-extinction burns may be a way to reduce eastern redcedar without affecting woodland communities.	High. However, more mechanical treatments may be needed.	Rare species may be of more concern in these sites. Prairie warbler is declining nationally, but restoration will improve habitat.

Table 16 (continued).

Ecosystem Type or Management Topic	Management Objectives (from Step 1)	Challenges to Meeting Management Objective with Climate Change	Opportunities for Meeting Management Objective with Climate Change	Feasibility of Meeting Management Objective under Current Management	Other Considerations
Woodland	Reduce eastern redcedar encroachment. Variable-intensity prescribed fire once every 3-4 years in beginning; move to 5-year rotation after four to five entries. Increase component of fire-tolerant species including shortleaf pine, white oak, post oak, and chinkapin oak. Thin timber; stand density will be variable based on site conditions across the landscape (aspect, soil type).	May need to shift timing of prescribed burns to align with seasonal changes in climate. Burn crews must be planned for months in advance, so it is hard to make last-minute changes to the timing of prescribed burns. May need to do some growing season burns for brush control; could run the risk of scarring hardwoods in the canopy. May be more challenging to do timber thinning if conditions are really wet during some seasons; there is an increased risk of tearing up the soil if it's too wet.	Can easily make changes to management if conditions change (more flexibility to make last-minute changes with harvest than with prescribed fire).	High. Assumption that funding remains available.	

Slow down to consider…

Table 17.—Example of a completed Step 4 worksheet for the Adaptation Workbook, drawn from the Jerktail Mountain adaptation demonstration (described in Chapter 6)

Ecosystem Type or Management Topic	Adaptation Actions		Time Frames	Benefits	Drawbacks and Barriers	Practicability of Tactic	Recommend Tactic?
	Approach	Tactic					
Igneous and dolomite glades	1.1. Reduce impacts to soils and nutrient cycling. 1.5. Restore or maintain fire in fire-adapted ecosystems.	Prescribed fire (variable intensity).	Every 3-4 years initially, shifting to every 5 years.	Releases potash, which is beneficial to species such as glade coneflower, southern blazing star, and other glade herbaceous species. There is a secondary benefit to pollinators. Glade species are fire-adapted. Generally few species that are at risk to fire on glades.	There are concerns about erosion from loss of litter and duff layer (especially before herbaceous layer is established) over the short term. (However, effects will be reduced if burning is done in March. Can shift to fall burn once herbaceous layer is established.) Could be beneficial to sericea lespedeza. Need to be careful about timing with Indiana bat breeding. Black bear could be negatively affected. Because this site is partially federally owned, time is needed to go through NEPA process. There is always a risk any time a prescribed burn is initiated.	High.	Yes.

Table 17 (continued).

Ecosystem Type or Management Topic	Adaptation Actions		Time Frames	Benefits	Drawbacks and Barriers	Practicability of Tactic	Recommend Tactic?
	Approach	Tactic					
Igneous and dolomite glades	4.1. Prioritize and maintain unique sites. 4.2. Prioritize and maintain sensitive or at-risk species or communities. 9.1. Favor or restore native species that are expected to be adapted to future conditions.	Mechanical reduction of eastern redcedar.	Gradual.	Maintains and restores biodiversity, increases sunlight to the ground. Reduces competition for light and nutrients to favor glade herbaceous species. Restores genetically viable populations. Restores a community of conservation concern (glades). Gradual reduction reduces risks of fuel-loading.	Time-consuming and costly. There can be localized scorching of the soil in areas where the redcedar was burned (short-term impact). Can create unnatural fuel loads if done incorrectly. Could damage post and chinkapin oaks with increased fuel load. Could create a niche where exotic species could come in.	High.	Yes.

Table 17 (continued).

Ecosystem Type or Management Topic	Adaptation Actions		Time Frames	Benefits	Drawbacks and Barriers	Practicability of Tactic	Recommend Tactic?
	Approach	Tactic					
Woodland	2.1. Maintain or improve the ability of forests to resist pests and pathogens. 5.2. Maintain and restore diversity of native species. 5.3. Retain biological legacies. 9.1. Favor or restore native species that are expected to be adapted to future conditions. 10.2. Allow for areas of natural regeneration to test for future-adapted species.	Selective thinning.	Every 20-30 years.	Provides timber (economic benefit). Increases light on the ground to promote a herbaceous layer. Helps reduce the risk of pest/pathogen outbreaks by reducing density.	This area has low accessibility for logging operations. Topography limits where logging can occur. Opens up the stand for adverse human use. Too much light can shock some of the timber and cause epicormic sprouting in oaks. Adds fuel-loading in short term. Logging equipment can disturb soil (which may be beneficial for shortleaf pine) and bring in exotic species.	High.	Yes.

Table 17 (continued).

Ecosystem Type or Management Topic	Adaptation Actions		Time Frames	Benefits	Drawbacks and Barriers	Practicability of Tactic	Recommend Tactic?
	Approach	Tactic					
Woodland	1.1. Reduce impacts to soils and nutrient cycling. 1.5. Restore or maintain fire in fire-adapted ecosystems. 3.3. Alter forest structure to reduce severity or extent of wind and ice damage. 9.1. Favor or restore native species that are expected to be adapted to future conditions.	Prescribed fire (variable intensity).	Every 3-4 years initially, shifting to every 5 years.	Creates conditions for regeneration of shortleaf pine (a climate-adapted species). Will increase herbaceous species abundance in the understory (which will help reduce erosion and maintain soil moisture). Reduces fuel loads. Improves habitat for game species. Improves habitat for some bird species.	There are concerns about erosion from loss of litter and duff layer (especially before herbaceous layer is established) over the short term. (However, effects will be reduced if burning is done in March. Can shift to fall burn once herbaceous layer is established.) Could be beneficial to sericea lespedeza. Need to be careful about timing with Indiana bat breeding. Black bear could be negatively affected. Because this site is partially federally owned, time is needed to go through NEPA process. There is always a risk any time a prescribed burn is initiated.	High.	Yes.

Table 18.—Example of a completed Step 5 worksheet for the Adaptation Workbook, drawn from the Jerktail Mountain adaptation demonstration (described in Chapter 6).

Ecosystem Type or Management Topic	Adaptation Monitoring Variable	Criteria for Evaluation	Monitoring Implementation
All forest types	Herbaceous species richness and cover	Jerktail woodland and glade: minimum of 20-percent increase in number of herbaceous species per quadrat in second year following second burn (90-percent confidence interval); increase mean percent cover of native herbaceous species by 50 percent after four burns.	Use the National Park Service Fire Monitoring Handbook plot design: two plots each in glades and woodlands. Baseline monitoring in June 2014 (year prior to first burn). Return first and second growing season after each burn.
	Density of pole-sized trees	Reduction in pole-sized trees 1-6 inches d.b.h. by at least 30 percent by the second growing season after the second burn. (Lower density indicates open woodland structure.)	
	Photo monitoring of visual changes in structure/ composition	Photo accuracy: Capture identical images within +/-5 percent of original image for comparison. (Shows structural and species changes toward desired condition.)	
	Fuel loads	Reduce fuel loads; reduce leaf litter depth by 50 percent by first year after second burn.	
	Tree basal area, growth, and composition	Increase in shortleaf pine, white oak, and chinkapin oak, and achievement of woodland structure.	Permanent inventory plots to be established.
	Shortleaf pine regeneration	Presence of shortleaf pine seedlings and saplings.	Qualitative observation.
	Tree mortality	Presence of dead/declining trees.	Visual observation.
	Exotic invasive species	Presence/absence, abundance.	Mapping, observation.
	Abundance, migration dates of birds (e.g., prairie warbler)	Increase in prairie warbler abundance on glades.	To be determined.
	Prescribed fire implementation	Coverage of fire implemented; visual changes postburn.	Before/after photos; mapping fire coverage.
Igneous and dolomite glades	Disturbance to ground from ATVs, feral hogs, and domestic/wild horse impacts	Extent of damage.	Visual observation.

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Forests across the United States are expected to undergo numerous changes in response to the changing climate. This second edition of the *Forest Adaptation Resources* provides a collection of resources designed to help forest managers incorporate climate change considerations into management and devise adaptation tactics. It was developed as part of the Climate Change Response Framework and reflects the expertise, creativity, and feedback of dozens of direct contributors and hundreds of users of the first edition over the last several years. Six interrelated chapters include: (1) a description of the overarching Climate Change Response Framework, which generated these resources; (2) a brief guide to help forest managers judge or initiate vulnerability assessments; (3) a "menu" of adaptation strategies and approaches that are directly relevant to forests of the Northeast and upper Midwest; (4) a second menu of adaptation strategies and approaches oriented to urban forests; (5) a workbook process with step-by-step instructions to assist land managers in developing on-the-ground climate adaptation tactics that address their management objectives; and (6) several real-world examples of how these resources have been used to develop adaptation tactics. The ideas, tools, and resources presented in the different chapters are intended to inform and support existing decisionmaking processes of multiple organizations with diverse management goals.

KEY WORDS: climate change, adaptation, forest, workbook, vulnerability assessment, urban forests, Northeast, Midwest, resilience

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